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GEOLOGY AND MINERAL RESOURCES OF THE BLOOMSBURG AND MIFFLINVILLE QUADRANGLES AND PART OF THE CATAWISSA QUADRANGLE, COLUMBIA COUNTY, PENNSYLVANIA

Jon D. Inners

**COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
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BUREAU OF
TOPOGRAPHIC AND GEOLOGIC SURVEY
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BLOOMSBURG AND MIFFLINVILLE
QUADRANGLES AND PART OF THE CATAWISSA
QUADRANGLE, COLUMBIA COUNTY,
PENNSYLVANIA**

by Jon D. Inners
Pennsylvania Geological Survey

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PREFACE

In this report with its accompanying maps and cross sections, the author describes the nature and distribution of rock formations and surficial deposits in a 309-km² (119.4-mi²) area in the vicinity of Bloomsburg, northeastern Pennsylvania. It is the second of a series of atlases that are designed to provide detailed descriptions of the geology, mineral resources, and groundwater resources in the vicinity of the Interstate Route 80 corridor between the North and West Branch valleys of the Susquehanna River. Special attention is paid to the wide variety of mineral resources in the area and to the influence of geology on such engineering problems as cut-slope stability, excavation difficulty, and foundation stability. Information is also provided on flood-prone areas and groundwater occurrence and quality.

In addition to providing useful data to the professional geologist, engineer, planner, and local official, it is hoped that this report will be found of benefit to the public and to students.

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ABSTRACT

The Bloomsburg and Mifflinville quadrangles and the northwest portion of the Catawissa quadrangle are situated in central Columbia County adjacent to the North Branch of the Susquehanna River and lie entirely within the Appalachian Mountain section of the Valley and Ridge physiographic province. Although the topography is controlled chiefly by the resistance to erosion of folded sedimentary rocks, depositional landforms that are directly or indirectly the result of continental glaciation are prominently developed in the northeast corner of the report area and along the Susquehanna River and its major local tributary, Fishing Creek. Exposed sedimentary rocks total approximately 4,250 m (14,000 ft) in thickness; overlying this bedrock sequence is a discontinuous, highly variable covering of unconsolidated surficial deposits up to 30 m (100 ft) thick.

Outcropping sedimentary rocks range in age from Middle Silurian to Late Mississippian and are divided into 16 formations. Shales, limestones, siltstones, and sandstones of open-marine to marginal-marine origin dominate the lower two thirds of the stratigraphic sequence (Middle Silurian Rose Hill Formation to Upper Devonian Irish Valley Member of Catskill Formation). Shales, sandstones, siltstones, and conglomerates of nonmarine origin form the upper one third of the sequence (Upper Devonian Sherman Creek Member of Catskill Formation to Upper Mississippian Mauch Chunk Formation).

The unconsolidated surficial deposits are all of Quaternary age and have been divided into 22 mappable units (including artificial fill). Pleistocene glacial and glaciofluvial deposits are recognized as belonging to three distinct episodes of glaciation (Illinoian, Altonian, and Woodfordian, in order of decreasing age) and are assigned rock-stratigraphic names (Muncy, Glen Brook, and Olean, respectively). Various types of colluvial deposits that formed largely in a rigorous late Woodfordian periglacial environment occur on moderate to steep slopes and fill the heads of many small valleys. A thin, discontinuous blanket of eolian silt and fine sand (Nescopeck Loess) that overlies bedrock and older surficial units in the vicinity of the Susquehanna River originated under these same periglacial

conditions. Holocene alluvial deposits are well developed along most streams.

The dominant geologic structures in the report area are, from south to north, the Berwick anticlinorium, Lackawanna synclinorium, and Milton anticlinorium. All three are first-order fold structures (wavelength greater than 10 km, or 6 mi) that plunge regionally to the east-northeast. A significant southeast-dipping displacement—the Light Street thrust fault—offsets Upper Silurian to Middle Devonian rocks on the north limb of the Berwick anticlinorium; smaller mapped faults on the south limb are poorly exposed and somewhat conjectural. Minor folds, kink bands, and wedge faults are conspicuous at numerous outcrops. On the Berwick anticlinorium, cleavage is well developed in shales, siltstones, and argillaceous limestones of the Rose Hill, Bloomsburg, Wills Creek, Mahantango, and Trimmers Rock Formations. Joints occur in all lithologies and generally are approximately perpendicular to bedding.

With the notable exception of flooding, environmental constraints related to geology in the Bloomsburg-Mifflinville area are generally not critical. Cut-slope stability, difficulty of excavation, and foundation strength of the bedrock units and surficial deposits vary greatly, but, except in rare cases, proper design should be able to overcome most problems, even in unfavorable areas. Although natural slopes are normally stable, earthflows, slumps, and translational slides may occur locally at times of catastrophic rainfall. Groundwater supplies adequate for domestic use can generally be obtained from bedrock at depths of 30 to 75 m (100 to 250 ft) anywhere in the area. Glaciofluvial gravels are a reliable source of water only in parts of the Fishing Creek and Huntington Creek valleys.

The major mineral resources of the report area are sand and gravel and crushed stone. Considerable potential also exists for the production of structural clay products and lightweight aggregate from clay shale. Although limestone, iron ore, particulate anthracite coal, and lead and zinc ores were at one time extracted on a significant scale, economic exploitation of these commodities in the future appears problematical. Possible but unproven resources include uranium and oil and natural gas.

INTRODUCTION

The area described in this report encompasses 309.0 km² (119.4 mi²) in the region of the North Branch of the Susquehanna River in Columbia County, northeastern Pennsylvania. In addition to the entire Bloomsburg and Mifflinville quadrangles, it includes that portion of the Catawissa quadrangle north of the Susquehanna River. The geology of the Berwick quadrangle,

adjoining the mapped area to the east, has been described in a recent report (Inners, 1978), and work is currently underway in the Washingtonville and Millville quadrangles to the west (Way, in preparation).

Principal centers of population within the mapped area are the town of Bloomsburg (approximately 11,000) and the western portion of the borough of Berwick (approximately 14,000). Both are situated on the north bank of the Susquehanna River, the former at the mouth of Fishing Creek and the latter about 16 km (10 mi) upstream to the northeast. Bloomsburg, long famous for its carpet manufacturing, is now probably best known as the home of Bloomsburg State College and as the site of the annual Bloomsburg Fair, one of the largest agricultural fairs in Pennsylvania. Berwick, on the other hand, produces a wide range of commercial and industrial commodities, including prepared foods, cigars, textiles, and fabricated metal goods. Other boroughs and villages of significant size include Mifflinville, Light Street, Orangeville (incorporated), Briar Creek (incorporated), Espy, Almedia, and Lime Ridge.

Much of the countryside surrounding these communities is utilized for grain and dairy farming. Residential housing developments are also spreading into the rural areas, particularly east of Bloomsburg and northwest of Berwick. A large Y-shaped mountain barrier that extends from the northeast into the mapped area is used mainly for hunting and other recreational pursuits. Small-scale logging operations are also periodically carried out in the mixed hardwood forests of second and third growth that cover these ridges.

Both existing and historic transportation routes within the mapped area follow the topographic grain of the landscape and trend approximately east-west. The main highways are Interstate Route 80 and U. S. Route 11, the former serving mainly for interregional transport and the latter for local and intraregional traffic. Most industrial and commercial establishments outside of the major population centers are situated along U. S. Route 11. The only operating rail lines, part of the Conrail system, parallel the Susquehanna River on its north and south sides. During the middle and latter part of the nineteenth century, the Pennsylvania Canal, North Branch Division, followed the north bank of the Susquehanna River across the report area.

Important previous geologic investigations in the Bloomsburg-Mifflinville area are those of Rogers (1858) and White (1883) on the bedrock formations; Lewis (1884), Leverett (1934), and Peltier (1949) on the surficial deposits; and Lohman (1937) on the groundwater resources. Recent mapping of the deposits associated with the Olean "terminal" moraine complex by Crowl and Sevon (1980) has been incorporated with minor modifications into the present report.



Figure 2. Knob Mountain, a narrow synclinal ridge formed by resistant Upper Devonian and Lower Mississippian sandstones and conglomerates, as seen from a hilltop 1.4 km (0.9 mi) south-southwest of Welliversville. The mountain terminates in a rocky promontory overlooking the borough of Orangeville.

their origin to a variety of processes not so directly related to lithologic variations. These include headward erosion along narrow zones of fractured bedrock, erosional sapping by water discharged from springs, and superposition from older erosion surfaces.

Although bedrock structure and lithology are the dominant controls on the topography of the Bloomsburg-Mifflinville area, Pleistocene glaciation also produced a variety of distinctive landforms. A hummocky kame moraine in Huntington Creek valley marks the terminal position of the Olean (Woodfordian, late Wisconsinan) ice sheet. Prominent meltwater terraces that also date from this latest glacial phase border the Susquehanna River entirely across the mapped area and are equally well developed on Fishing and Huntington Creeks. Fluvial terraces along Little Fishing Creek, Green Creek, and Hemlock Creek formed at the same time as the glacio-fluvial terraces at similar elevations on the proglacial streams. The lowest terrace on all these streams has been strongly modified by recent alluviation and forms the present floodplain.

Pre-Woodfordian (Muncy and Glen Brook) glacial drift is widely distributed over the mapped area, but generally has limited topographic expression. An important exception is the high, flat-topped mound of Muncy (Illinoian) gravel that extends across the divide between Fishing Creek and the Susquehanna River about 1.2 km (0.7 mi) south of Light Street. In other areas, old glacial drift has a smooth expression and relatively featureless topography, as in the valley of the West Branch of Briar Creek, in the vicinity of Buckhorn, and in Greenwood Valley.

The report area is situated entirely within the drainage basin of the North Branch of the Susquehanna River. Two major drainage networks tributary to the Susquehanna lie on the north side of the river. These are the extensive Fishing Creek system, whose major feeder streams rise on North Mountain (the Allegheny Front) about 35 km (22 mi) north of Bloomsburg, and the much smaller, but equally intricate, Briar Creek system, which is composed mainly of streams that originate either on Knob and Lee Mountains or on the upland directly to the south. Little Shickshinny Creek, a tributary of Shickshinny Creek, drains most of the cove valley between Huntington and Lee Mountains.

On the south side of the Susquehanna, all but a small percentage of the area drains into the river by minor streams that are incised into the upland north of Nescopeck Mountain. The largest of these is Tenmile Run, which enters the Susquehanna southwest of Mifflinville. A small area in Mifflin Township (southeast corner of the Mifflinville quadrangle) is drained by an unnamed tributary of Nescopeck Creek, and an equally small tract in Main Township (extreme south-central part of the mapped area) drains into Catawissa Creek.

Two particularly intriguing physiographic features in the report area are the funnel-shaped valley of Tenmile Run south of Mifflinville and the “umlaufberg,” or isolated bedrock knob, west of Orangeville. Both apparently owe their origin to complex drainage adjustments brought about by pre-Woodfordian glaciations (D. D. Braun, personal communication), but their precise nature is unclear. The Tenmile Run valley is probably an ancient channel of the Susquehanna River that has been strongly modified by pre-Woodfordian glacial erosion. The Orangeville “umlaufberg” was formed by a series of glacial diversions of Fishing Creek around and through a bedrock spur, also in pre-Woodfordian time.

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STRATIGRAPHY

The stratigraphic succession in the Bloomsburg-Mifflinville area consists of two distinct divisions—a bedrock sequence that ranges in age from Middle Silurian to Late Mississippian (415 to 325 million years old) and a thin, unconsolidated, blanketing surficial sequence of Quaternary age (less than 1 million years old). The 16 bedrock formations total about 4,250 m (14,000 ft) in thickness and are predominantly brackish to marine limestones, shales, and siltstones in the lower two thirds (Rose Hill Formation to Irish Valley Member of the Catskill Formation) and nonmarine shales, sandstones, and conglomerates in the upper one third (Sherman Creek Member of the Catskill Formation to Mauch Chunk Formation). Quaternary surficial deposits comprise numerous unconsolidated lithologic units that overlie bedrock in more than half of the mapped area. The thickness of these surficial materials ranges from less than 1 m (3 ft) to nearly 30 m (100 ft).

SILURIAN SYSTEM

Rose Hill Formation

STRATIGRAPHIC COMMENT: The Rose Hill Formation in the report area consists of three mappable subdivisions—an unnamed lower member, the medial Centre Member, and an unnamed upper member.

LITHOLOGY: The lower member is predominantly clay shale and silty clay shale that contains common interbeds of very fine to medium-grained, frequently iron-rich, calcareous sandstone. Invertebrate fossils (brachiopods and crinoids) are common.

The Centre Member is mostly fine- to medium-grained quartzose sandstone that has a hematite cement (“iron-sandstone”); some interbedded

silty clay shale occurs in the middle and upper parts. Claystone clasts to 10 cm (4 in.) in diameter are common in sandstone throughout the outcrop belt, and quartz granules to 3 mm (0.1 in.) occur west of Hemlock Creek. Ichnofossils¹ cover many bedding planes, but invertebrate body fossils are rare.

The upper member is mostly interbedded calcisiltite, silty clay shale, and very fine to fine-grained sandstone; in the upper part, intercalations of bio-skeletal calcarenite and calcirudite occur, some of which contain appreciable hematite (“fossil ore”). Invertebrate fossils (brachiopods, trilobites, and crinoids) are abundant.

COLOR: Shales of the lower member are light grayish blue green to light olive gray and greenish gray. Sandstones in this interval are medium light gray, commonly weathering dark reddish brown due to a high iron content.

The Centre Member is predominantly grayish red purple and dusky red. Many of the shales interbedded with the “iron-sandstones” are light olive gray and mottled light olive gray and grayish red purple.

Upper member rocks are medium gray, light olive gray, and grayish red.

BEDDING: The lower member is thin to medium bedded.² Most sandstone beds are lenticular and finely cross laminated and some exhibit load casts and ball-and-pillow structure; bedding partings are smooth.

The Centre Member is dominantly medium to very thick bedded, but some thin beds occur in the middle and upper parts. Sandstones are intensely bioturbated and have wavy, irregular bedding surfaces; some individual beds pinch and swell along outcrops; where bioturbation has not disrupted bedding, most sandstone units are planar bedded; ripple marks are common on the tops of beds.

The upper member is mostly medium bedded and has wavy bedding surfaces.

THICKNESS: The Rose Hill is approximately 278 m (900 ft) thick. The lower member is 220 m (720 ft) thick, but only the upper 160 m (525 ft) is exposed at the surface. The Centre Member is 18 m (60 ft) thick and the upper member is 40 m (130 ft) thick.

CONTACTS: The lower contact (with the quartzites of the Tuscarora Formation) is not exposed in the report area. The upper contact is sharp, but

¹ Refer to glossary for explanation of technical terms not defined in text.

² Bed thicknesses used in this report are as follows:

Laminated	<1 cm (<3/8 in.)
Thin	1 to 5 cm (3/8 to 2 in.)
Medium	5 to 60 cm (2 in. to 2 ft)
Thick	60 to 120 cm (2 to 4 ft)
Very thick	>120 cm (>4 ft)

conformable, and is marked by an abrupt increase in grain size from clay, silt, and very fine sand to medium sand in adjacent beds.

ORIGIN: The shales and interbedded thin sandstones of the lower member were probably deposited in a relatively quiet, moderately deep (30 to 150 m, or 100 to 500 ft) marine environment. The iron-rich Centre Member represents deposition of shallow subtidal to possibly intertidal sands. The “fossil-ore”-bearing (iron-rich) shales, sandstones, and limestones of the upper member accumulated on a shallow subtidal, open-marine shelf (Hunter, 1970).

BEST EXPOSURES: The lower member is well exposed along Hemlock Township Route 360 in the southwestern part of the gap at Fernville (41°00'27"N/76°28'03"W), and in a borrow pit on the east side of Iron Street, Bloomsburg, in the northeastern portion of the same gap (41°00'46"N/76°27'58"W). The Centre Member is exposed in abandoned quarries on the west side of Hemlock Township Route 360 at opposite ends of the gap at Fernville (41°00'50"N/76°28'33"W and 41°00'24"N/76°27'56"W), and along the old Bloomsburg Iron Company canal, about 1.8 km (1.1 mi) north of the Bloomsburg town square (41°00'54"N/76°28'18"W). The upper member is exposed in an abandoned quarry on the old railroad grade south of Fishing Creek, about 1.9 km (1.2 mi) north of Bloomsburg (41°01'16"N/76°27'30"W).

FIELD OCCURRENCE: The Rose Hill Formation underlies the nearly continuous anticlinal (Berwick anticlinorium) highland formed by Montour Ridge (west of Hemlock Creek), the unnamed ridge between Hemlock and Fishing Creeks, and Turkey Hill. Float consists of chippy clay shale and platy sandstone (lower member), blocky and rubbly, hard, ferruginous sandstone (Centre Member), and platy to slabby, fossiliferous sandstone and chippy clay shale mixed with solution-rounded pebbles of limestone (upper member). Natural outcrops of the Centre Member are common, but the lower and upper members are exposed mainly in man-made cuts and excavations.

Keefer Formation

LITHOLOGY: The lowermost part is fine- to medium-grained, fossiliferous, quartzitic sandstone that contains lenses of light-olive-gray claystone clasts. The upper three fourths is predominantly alternating very fine to fine grained, cross-laminated sandstone and sand-silt laminite intercalated with silty clay shale. The most abundant fossils are brachiopods and crinoids (columnals).

COLOR: Sandstones are medium light gray and weather yellowish gray with reddish-brown speckles. Shales are medium dark gray and olive gray.

BEDDING: The Keefer is predominantly thin to medium bedded; the basal sandstone is thick bedded.

THICKNESS: 12 m (39 ft).

CONTACTS: The lower contact is conformable and sharp, being marked by a 0.6- to 0.9-m- (2.0- to 2.9-ft-) thick sandstone bed at the base of the Keefer. The upper contact is also conformable and sharp, and is defined as the top of a 0.3-m (1.0-ft) bed of highly fossiliferous (brachiopod-rich), calcareous sandstone.

ORIGIN: The basal Keefer sandstone was deposited in a shallow, near-shore environment, probably along a prograding, regressive marine shoreline (Luttrell, 1968; Faill and Wells, 1974). The finer grained, upper part of the formation suggests sedimentation in somewhat deeper, quieter waters during a transgressive phase.

BEST EXPOSURES: Good exposures of the Keefer Formation occur along the abandoned railroad grade on the south side of Fishing Creek, 1.9 km (1.2 mi) north of Bloomsburg (41°01'17"N/76°27'35"W); behind a private dwelling on the west side of Hemlock Township Route 360 at the north edge of Fernville (41°00'20"N/76°27'54"W); and on the west side of Hemlock Creek, 122 m (400 ft) northwest of the Legislative Route 19119 bridge (40°59'45"N/76°29'17"W).

FIELD OCCURRENCE: The Keefer occurs on the lower slopes of the Montour Ridge-Turkey Hill anticlinal highland, where it locally forms broad dip slopes. Float consists of fossiliferous, blocky and slabby, medium-grained sandstone; platy and flaggy, fine-grained sandstone; and chippy clay shale. Outcrops are rare, being restricted to artificial excavations, gullies, and deep stream valleys.

Mifflintown Formation

LITHOLOGY: The lower half of the Mifflintown is predominantly calcareous clay shale containing interbeds of coarsely crystalline, bioskeletal calcarenite that are more common upward. The upper half of the formation consists of interbedded calcisiltite and calcareous clay shale. Some coarser calcisiltite beds contain subrounded, flattened intraclasts, 2 cm (1 in.) or more in maximum diameter, of fine, laminated calcisiltite (intraformational conglomerate). Small stromatolitic laminations are common in the upper limestones. Also characteristic of the upper half of the Mifflintown are semispherical to lozenge-shaped, bioskeletal calcisiltite mounds up to 1 m (3 ft) in diameter and 0.3 m (1 ft) thick (Figure 3). These mounds consist of abundant gastropod, ostracode, and bryozoan fragments in a calcisiltite



Figure 3. Bioskeletal calcisiltite mound in the upper part of the Mifflintown Formation, along an abandoned railroad grade on the south side of Fishing Creek about 1.9 km (1.2 mi) north of Bloomsburg ($41^{\circ}01'28''\text{N}/76^{\circ}26'48''\text{W}$). Note the rough surface of the mound and the deformation (loading) of underlying beds. The staff is 1.5 m (5 ft) long.

matrix. Other fossils occurring in the Mifflintown include brachiopods, crinoids (columnals), and small bivalves.

COLOR: Mifflintown lithologies are dark gray to medium dark gray, weathering light gray and light olive gray, except for an approximately 1 m (3 ft) thick, grayish-red claystone in the uppermost part.

BEDDING: Clay shale is medium to thick bedded in the lower half of the formation, and thin to medium bedded in the upper half. The limestones are thin to medium bedded, and have undulatory bedding surfaces; very fine laminations are commonly evident on weathered fractures.

THICKNESS: 60 m (200 ft).

CONTACTS: The lower contact is conformable and sharp. The upper contact is conformable and interbedded and is defined as the top of a thick, medium-gray to light-olive-gray calcareous shale and calcisiltite interval that overlies a 1-m- (3-ft-) thick, grayish-red claystone.

ORIGIN: The Mifflintown Formation exhibits a gradual vertical change in interpreted depositional environments from shallow subtidal, but mostly below effective wave base, in the lower part of the formation, to very shallow subtidal (above wave base) in the upper part. The small laminated stromatolitic structures in the upper part probably formed in shallow, protected lagoons that were periodically disturbed by storm waves. Semiconsolidated lime-mud fragments torn up by these storm waves and reincorporated into the sediment formed the intraformational conglomerates. The origin of the mounds is somewhat problematical, but they may have formed by the algal cementation of shelly debris that was concentrated by wave or current action.

BEST EXPOSURES: The upper part of the Mifflintown Formation is exposed at several spots along the abandoned railroad grade on the south side of Fishing Creek, about 2 km (1.2 mi) north of the Bloomsburg town square (41°01'19"N/76°27'40"W and 41°01'28"N/76°26'48"W), and also along Hemlock Township Route 360, 1.8 km (1.1 mi) northwest of Fernville (41°00'58"N/76°28'38"W). Shales in the lower part are exposed along Legislative Route 239 (Iron Street extended), 2.1 km (1.3 mi) north of Bloomsburg (41°01'05"N/76°28'11"W).

FIELD OCCURRENCE: The formation forms a belt of narrow, longitudinal valleys on the flanks of the Montour Ridge-Turkey Hill anticlinal highland. East-northeast of Turkey Hill, the outcrop trace is generally covered by Muncy till and stratified drift. Where the Mifflintown is not covered by surficial deposits, its float of mixed chippy shale and solution-rounded plates and slabs of fossiliferous limestone is conspicuous. Natural outcrops occur only along a few deeply incised streams.

Bloomsburg Formation

LITHOLOGY: The Bloomsburg Formation is predominantly hackly, silty claystone and poorly fissile, silty clay shale, containing frequent interbeds of siltstone and sandstone. Sandstone beds are particularly conspicuous in the upper part (Moyer Ridge Member). The claystones and clay shales are locally calcareous and often exhibit irregular, curved, slickensided surfaces. The sandstones are very fine to medium grained, micaceous, and poorly

sorted; lithic grains are abundant. Near the base of the formation, there is at least one thin interval of interbedded, sparsely fossiliferous, calcareous clay shale and calcisiltite (transition with the Mifflintown Formation).

COLOR: Predominantly grayish red to reddish brown. Several thin, olive-gray to medium-light-gray intervals occur in the lower part, and some greenish-gray mottling is present in the upper part.

BEDDING: Claystones and clay shales are medium to very thick bedded, and are usually mud cracked and bioturbated. Sandstones and siltstones are thin to medium bedded, and are generally 30 cm (1 ft) or less in thickness; the boundaries of the coarser beds are not sharply defined, but are in many places accentuated by regular, closely spaced joints that terminate at upper and lower bedding surfaces. (These joints are caused by the brittle behavior of the sandstone and siltstone beds during deformation, as contrasted to the ductility of the enveloping claystones.)

THICKNESS: Approximately 152 m (500 ft) is exposed at the type section along the old Bloomsburg Iron Company railroad grade on the south bank of Fishing Creek at Bloomsburg ($41^{\circ}00'15''\text{N}/76^{\circ}27'39''\text{W}$). The Moyer Ridge Member, the top of which occurs about 36 m (118 ft) below the top of the formation, is 7.9 m (26 ft) thick at this locality (Hoskins, 1961).

CONTACTS: The lower contact is conformable and interbedded with the underlying Mifflintown Formation. It is defined as the base of the second red bed (in ascending order) of an 18-m- (60-ft-) thick interbedded red-non-red sequence. The upper contact is also conformable, and is interbedded with the overlying Wills Creek Formation; it is placed at the top of the "solid red" beneath the first olive-gray shale bed in a transitional sequence which is included entirely within the Wills Creek.

ORIGIN: The red, fine-grained clastic sediments of the Bloomsburg Formation in the mapped area are transitional between somewhat coarser grained, fluvial deposits of the same general age to the east and southeast, and fossiliferous, lagoonal sediments to the west and southwest (Hoskins, 1961). Most likely these rocks represent deltaic sediments deposited in near-shore, slightly brackish lagoons or freshwater portions of coastal embayments into which the sluggish, low-gradient streams that deposited the eastern phase of the Bloomsburg emptied. The intense bioturbation of some claystone beds shows that organisms were at least locally abundant, although their actual fossil remains were destroyed by oxidation during the periods of subaerial exposure that formed the mud cracks. The Moyer Ridge sandstones probably accumulated during a major progradation of the Bloomsburg delta complex.

BEST EXPOSURES: The Bloomsburg is widely exposed in the report area. In addition to the type section mentioned above, other good partial exposures are: (1) a cut on the east side of Pa. Route 42, 2.0 km (1.2 mi) southwest of the Bloomsburg town square ($40^{\circ}59'44''\text{N}/76^{\circ}28'49''\text{W}$); (2) along Legislative Route 19026 on the north side of Fishing Creek valley between the Bloomsburg landfill and Camp Creasy ($41^{\circ}01'31''\text{N}/76^{\circ}27'44''\text{W}$ to $41^{\circ}01'40''\text{N}/76^{\circ}26'59''\text{W}$); (3) along Pa. Route 487 at the edge of the Bloomsburg State College campus ($41^{\circ}00'30''\text{N}/76^{\circ}27'00''\text{W}$); and (4) along U. S. Route 11, about 1.6 km (1 mi) west of Briar Creek ($41^{\circ}02'34''\text{N}/76^{\circ}18'12''\text{W}$). The latter locality exhibits a good exposure of the Moyer Ridge Member. The Mifflintown-Bloomsburg contact crops out along the abandoned railroad grade on the south side of Fishing Creek 2.1 km (1.3 mi) north of Bloomsburg ($41^{\circ}01'19''\text{N}/76^{\circ}27'41''\text{W}$). The contact with the overlying Wills Creek Formation can be best observed on the northeast side of Hemlock Creek about 300 m (1,000 ft) above its confluence with Fishing Creek just west of Bloomsburg ($40^{\circ}59'46''\text{N}/76^{\circ}28'41''\text{W}$), and in Dillons Hollow, 0.7 km (0.4 mi) east of the Bloomsburg State College campus ($41^{\circ}00'36''\text{N}/76^{\circ}26'26''\text{W}$).

FIELD OCCURRENCE: The formation underlies a belt of low hills on both sides of the Montour Ridge-Turkey Hill anticlinal highland and also forms a wide area of rolling upland terrain extending from the Scott-North Centre Township line east-northeastward to the forks of Briar Creek. Grayish-red, chippy to hackly claystone float, mixed with some platy siltstone and sandstone float, is common in plowed fields and shallow artificial excavations, except where the formation is covered by Muncy drift or Nescopeck Loess. The outcrop trace of the Moyer Ridge Member is marked by slabby to chippy sandstone fragments and pieces of comb-like vein quartz. The Bloomsburg crops out mainly in man-made cuts and excavations, but does occur as steep natural bluffs along some streams such as Hemlock Creek and Little Fishing Creek.

Wills Creek Formation

LITHOLOGY: The dominant lithology in the Wills Creek Formation is shaly calcareous claystone; argillaceous dolosiltite and calcisiltite and calcareous siltstone form conspicuous interbeds, and very fine to fine-grained sandstone is a minor component. Calcisiltites are locally stromatolitic. Mud cracks are abundant throughout.

COLOR: The shaly claystones are mostly greenish gray, but some grayish-red to grayish-red-purple intervals occur in the lower half. The carbonates are medium gray, weathering yellowish gray to light greenish gray. Siltstones and sandstones are yellowish gray and pale purplish gray.

BEDDING: Claystones are laminated to thick bedded. Carbonates are finely laminated to medium bedded. Siltstones and sandstones are thin to medium bedded, and are commonly finely cross laminated. Massive, structureless, hackly weathering, argillaceous dolosiltite beds to 0.5 m (1.6 ft) thick are particularly characteristic of the upper part of the formation.

THICKNESS: Approximately 200 m (650 ft).

CONTACTS: The lower contact is within an interbedded succession several tens of meters (about 100 ft) thick and is drawn at the base of the lowest greenish-gray unit. The upper contact is gradational and also within an interbedded succession; it is defined as the boundary between a shaly interval that contains massive beds of yellowish-gray- to light-olive-gray-weathering, argillaceous dolosiltite and a thick sequence of laminated calcisiltites typical of the Tonoloway Formation (Figure 4).

ORIGIN: The Wills Creek Formation is composed predominantly of intertidal to supratidal mudflat and shallow lagoonal deposits. The abundant mud cracks are evidence of frequent periods of subaerial desiccation; the algal stromatolites formed in very shallow, probably somewhat hypersaline



Figure 4. Contact of the Tonoloway (Sto) and Wills Creek (Swc) Formations in an abandoned quarry on the north side of U. S. Route 11, 0.6 km (0.4 mi) northwest of Almedia (41°01'01"N/76°23'43"W). Note the well-developed kink fold. The staff is 1.5 m (5 ft) long.

lagoons. Quartz grains in at least one fine-grained sandstone bed appear to be frosted and were probably wind-transported.

BEST EXPOSURES: Nearly the entire Wills Creek Formation is exposed along Legislative Route 19026 immediately northwest of Camp Creasy (41°01'48"N/76°26'57"W). Good natural exposures of the lower Wills Creek are present on the steep west bank of Little Fishing Creek, 1.6 km (1.0 mi) east of Buckhorn (41°01'15"N/76°28'48"W). The contact with the overlying Tonoloway can be observed in an abandoned quarry on the steep bluff north of U. S. Route 11, 0.6 km (0.4 mi) northwest of Almedia (Figure 4).

FIELD OCCURRENCE: The Wills Creek Formation underlies belts of subdued topography north and south of the Montour Ridge-Turkey Hill highland and its extension northeastward to Briar Creek. Generally this terrain is 15 to 30 m (50 to 100 ft) lower than that developed on the Bloomsburg Formation. At Briar Creek borough and in the western part of Berwick, the Wills Creek is entirely covered by Olean terrace gravel. Distinctive yellowish-gray and olive-gray, chippy and splintery (shale and claystone), hackly and platy (carbonate), and slabby and flaggy (sandstone and siltstone) float is conspicuous in fields and shallow roadcuts where it is not masked by surficial deposits. This formation is exposed in many highway and railroad cuts and small borrow pits; a few natural outcrops occur in deep stream valleys.

Tonoloway Formation

LITHOLOGY: The lower part is predominantly laminated dolomitic calcisiltite and dolosiltite. The upper part is relatively pure, laminated calcisiltite characterized by very thin wisps of fine calcarenite; fine, calcitic "birdseye" structure occurs in some beds, and a few intervals of flat-pebble (intraformational) conglomerate are present. Calcareous clay shale interbeds occur throughout, but are thicker and more numerous in the lower part. Mud cracks are abundant in both portions, and salt casts were observed locally in the lower beds. Large ostracodes (mostly *Leperditia*) are the only conspicuous fossils. Sphalerite (zinc sulfide) and galena (lead sulfide) are locally associated with calcite veins in the lower and middle part of the formation, as described more fully in the "Mineral Resources" section of this report.

COLOR: Medium gray to medium dark gray. Weathering colors vary from light gray and yellowish gray (calcisiltites) to light brownish gray (dolosiltites) and light olive gray (lower shales).

BEDDING: Calcisiltites and dolosiltites are predominantly laminated to thin bedded, and only rarely medium bedded. Shale interbeds are laminated

to thin in the upper part, but may exceed 0.3 m (1.0 ft) in thickness in the lower. Carbonate beds in the upper part are often wavy and lenticular, and sometimes cross laminated. Some beds contain laminated, convex-upward structures having relief up to 1 m (3 ft); these occur in the upper part and may be of algal origin.

THICKNESS: Approximately 60 m (200 ft), divided roughly equally between the lower dolomitic portion and the upper limy portion.

CONTACTS: The lower contact with the Wills Creek Formation is conformable and interbedded; it is defined as the top of a dominantly shaly interval that contains massive beds of argillaceous dolosiltite (Figure 4). The upper contact is sharp, but conformable; it is marked by an abrupt change from laminated, sparsely fossiliferous, pure calcisiltites of the upper Tonoloway to nodular, highly fossiliferous, argillaceous calcisiltites of the lower Keyser Formation (Figure 5).

ORIGIN: Deposition of the Tonoloway took place mostly in shallow lagoons and on adjacent intertidal mudflats. The fine laminations were

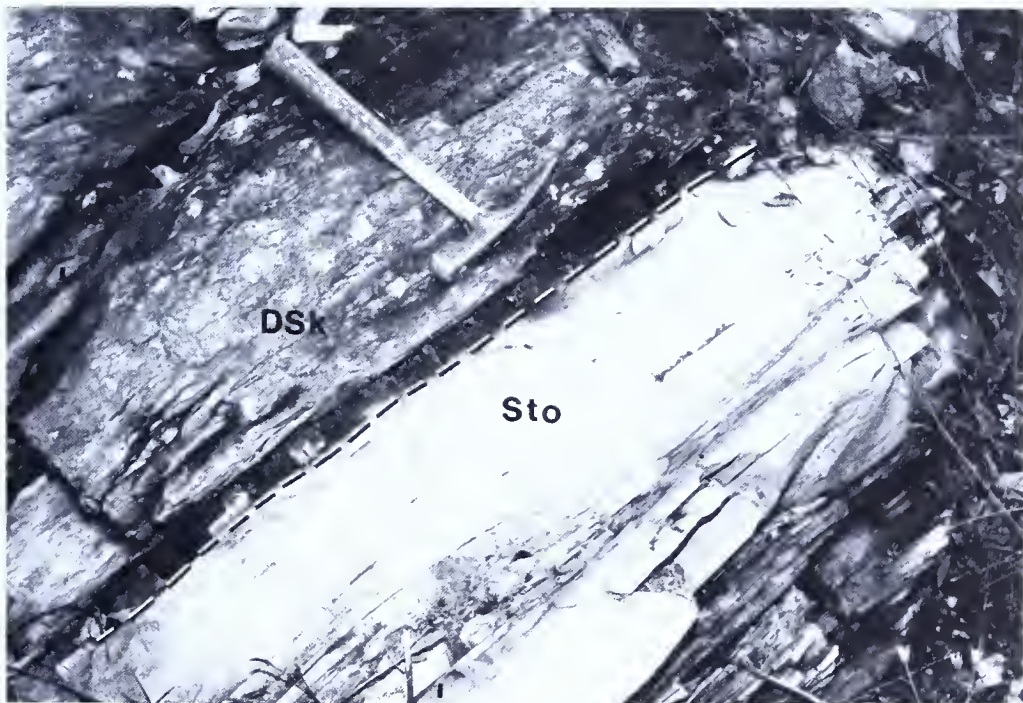


Figure 5. Abrupt contact of nodular, argillaceous limestone of the Keyser Formation (Byers Island Member) (DSk) and underlying laminated, pure limestone of the Tonoloway Formation (Sto), in an abandoned quarry on the north side of U. S. Route 11, 1.1 km (0.7 mi) northwest of Lime Ridge (41°01'45"N/76°21'06"W). Note the conspicuous cross laminations in the Tonoloway Formation. The hammer is 28 cm (11 in.) long.

formed in part by thin films of algae that caused the deposition of lime mud through the removal of carbon dioxide from warm lagoonal waters. The lower part of the formation is probably in part of supratidal origin, as suggested by its high dolomite content and by the local occurrence of salt casts (see Lucia, 1972).

BEST EXPOSURES: Numerous abandoned quarries on the north side of U. S. Route 11 between Almedia and Lime Ridge expose portions of the Tonoloway; good examples are behind and just east of Terrapin Station Restaurant (formerly Dave's Sea Food House) (41°01'12"N/76°23'06"W), and behind the S and B Foundry, 0.4 km (0.2 mi) to the northeast. Other partial exposures are (1) on Legislative Route 19037 at the east end of the large abandoned Lime Ridge quarry (41°01'49"N/76°21'01"W); (2) along the abandoned railroad grade on the south side of Fishing Creek 0.5 km (0.3 mi) north of Paper Mill (41°02'04"N/76°26'20"W); and (3) along another abandoned railroad on the south bank of the West Branch of Briar Creek, 1.0 km (0.6 mi) east of Dennis Mills (41°03'38"N/76°18'27"W).

FIELD OCCURRENCE: The Tonoloway, in conjunction with the overlying Keyser and Old Port Formations, forms a discontinuous, but locally conspicuous ridge on the south flank of the Berwick anticlinorium—notably west of Fishing Creek and on the north side of U. S. Route 11 between Almedia and Lime Ridge. On the north flank of the anticlinorium, the Tonoloway is either locally faulted out, or has weak topographic expression as a result of fault elimination of the Keyser and Old Port. Platy to flaggy limestone and dolomite float of the Tonoloway is very distinctive, but the outcrop trace is generally covered by surficial deposits. Natural exposures are very rare. Solution cavities and travertine-coated surfaces are present in some quarry exposures, but the Tonoloway appears to be less prone to solution than the overlying Keyser Formation.

DEVONIAN-SILURIAN TRANSITION

Keyser Formation

STRATIGRAPHIC COMMENT: Throughout much of central Pennsylvania the Keyser Formation can be readily subdivided into three members characterized by distinctive limestone lithologies. Head (1969) named these members (in ascending order) Byers Island, Jersey Shore, and LaVale. Although these three subdivisions of the Keyser can be recognized in the Bloomsburg-Mifflinville area, they are too thin and poorly exposed to map separately.

The presence of Silurian fossils in the lower part of the Keyser Formation and Devonian fossils in the upper part indicates that the systemic time boundary lies within this stratigraphic unit (Berdan, 1964; Bowen, 1967).

LITHOLOGY: The lower 9 to 11 m (30 to 35 ft) of the Keyser is predominantly nodular, fossiliferous, argillaceous calcisiltite and fine calcarenite, containing a basal unit (probably less than 3 m (10 ft) thick) of pure, fossiliferous, “birdseye” calcilutite in the western portion of the mapped area (Byers Island Member). The middle 15 m (50 ft) is mostly highly fossiliferous calcarenite with some interbedded calcareous shale; a 1.0- to 3.6-m- (3.3- to 12-ft-) thick, sparry, stromatoporoid biostrome is locally developed at the top (Jersey Shore Member). The upper 12 m (39 ft) of the Keyser is dolomitic calcisiltite, in many places containing considerable interbedded calcareous clay shale (LaVale Member). Invertebrate fossils, abundant and locally silicified in the lower and middle parts, include brachiopods, corals (favositid, halysitid, and rugose types), crinoids, gastropods, and stromatoporoids.

COLOR: Limestones in the lower part of the Keyser are medium dark gray to dark gray and bluish gray; those in the middle and upper part are medium gray. The calcareous shales are medium dark gray. Both the calcareous shales and the limestones weather light gray, except for siliceous zones which weather light yellowish brown.

BEDDING: The lower and middle parts of the Keyser are thin to thick bedded and have irregular, wavy bedding partings. The upper part is laminated to thin bedded, displaying an even parting.

THICKNESS: A 38-m (125-ft) section measured in the Grovania quarry of the Lycoming Silica Sand Company, 5.5 km (3.4 mi) southwest of Bloomsburg (40°58'38"N/76°30'59"W, Danville quadrangle) is believed to be close to the average thickness of the Keyser in the mapped area.

CONTACTS: The basal contact is sharp and conformable. The upper contact is also sharp and conformable, and is characterized by a change from laminated, dolomitic calcisiltite to cherty, fossiliferous calcarenite or dark-gray, calcareous clay shale of the overlying Old Port Formation.

ORIGIN: The lower two thirds of the Keyser Formation was deposited mainly in a shallow marine, subtidal shelf environment. In shallower and more oxygenated, nutrient-rich areas, colonial corals and stromatoporoids locally proliferated to form broad blankets of low relief that may have been partially exposed at low tide. The upper third of the formation accumulated in shallow lagoons and on intertidal mudflats similar to those interpreted for Tonoloway deposition.

BEST EXPOSURES: The Keyser Formation is almost completely exposed in several abandoned quarries on the grounds of the Berwick Golf Club, 0.6

km (0.4 mi) south of Martzville (about $41^{\circ}03'54''\text{N}/76^{\circ}15'54''\text{W}$). Other good exposures of portions of the Keyser include: (1) abandoned quarries north of Montour Township Route 476 (old U. S. Route 11), 1.1 km (0.7 mi) northwest of Rupert ($40^{\circ}59'03''\text{N}/76^{\circ}29'09''\text{W}$); (2) the west side of Little Fishing Creek and in an abandoned quarry on the south side of Pa. Route 42, 1.75 km (1.1 mi) northeast of Buckhorn (approximately $41^{\circ}01'32''\text{N}/76^{\circ}28'53''\text{W}$) (mainly upper part); and (3) in a cut on Legislative Route 19037 at the east end of the abandoned Lime Ridge quarry ($41^{\circ}01'47''\text{N}/76^{\circ}20'56''\text{W}$) (lower part).

FIELD OCCURRENCE: The Keyser Formation forms the middle to upper part of a low, discontinuous ridge on the south flank of the Berwick anticlinorium. On the north flank, where the formation is generally cut out by the Light Street fault, distinct Keyser topographic expression (as low rolling hills) occurs only at the Berwick Golf Club near Martzville. The formation is covered by Olean terrace gravels from Bloomsburg to Briar Creek, and at Berwick. The Keyser weathers to rubbly, platy, and slabby, solution-rounded fragments in a deep orangish-red soil. Float fragments are rarely encountered, however, because of a nearly complete surficial cover. Although natural outcrops are very rare, the Keyser is exposed in numerous old quarries. Small caves with associated flowstone have been noted in the Keyser at the Berwick Golf Club and in an abandoned quarry about 0.5 km (0.3 mi) downstream of Briar Creek Lake ($41^{\circ}03'48''\text{N}/76^{\circ}16'32''\text{W}$). Cavernous Keyser limestone was also encountered in a drilled water well on the south side of U. S. Route 11 at the Lime Ridge plant of Poloron Products, Inc. ($41^{\circ}01'45''\text{N}/76^{\circ}20'49''\text{W}$).

DEVONIAN SYSTEM

Old Port Formation

STRATIGRAPHIC COMMENT: In the report area, the Old Port Formation is a thin, poorly exposed, laterally variable unit that includes, at least locally, intervals of limestone, sandstone, shale, and chert. Members recognized in the Williamsport area to the northwest by Faill and others (1977), namely (in ascending order) the New Creek-Corriganville,¹ Mandata, Shriver, and Ridgeley, can be differentiated at least locally, but in general these subdivisions are thinner than in surrounding areas and cannot be mapped in the report area. The most notable change occurs in the Ridgeley Member, which consists of about 30 m (100 ft) of calcareous sandstone near Williamsport but is recognizable as only 0.6 m (2 ft) of sandy chert near Buckhorn in the southwestern part of the Bloomsburg quadrangle. To the south and east, even this sandy chert apparently disappears. Rigorous un-

¹ Faill and others (1977) included the New Creek Member within their Corriganville Member.

derstanding of stratigraphic changes within the Old Port is seriously hampered by surficial cover and by probable fault elimination on the north limb of the Berwick anticlinorium.

LITHOLOGY: A generalized, composite lithologic sequence for the Old Port Formation near Bloomsburg is as follows (in ascending order): (1) probable New Creek-Corriganville Members—cherty, fossiliferous calcarenite and shaly calcisiltite, having a distinctive medium-grained, fossiliferous, calcareous quartz sandstone (“Grovania” sandstone) about 1 m (3 ft) above the base (see White, 1883, and Reeside, 1918); (2) probable Mandata Member—subfissile to platy, somewhat calcareous, slightly silty clay shale, containing argillaceous calcisiltite interbeds in the upper part; and (3) probable Shriver-Ridgeley Members—brittle, slightly calcareous chert capped by a thin band of fine, sandy, highly fossiliferous chert. Invertebrate fossils are abundant in the limestones and cherts of the Old Port Formation, the most conspicuous types being brachiopods (pentamerids, spiriferids, and strophomenids), crinoids (columnals), and gastropods (platyceratids).

COLOR: The New Creek-Corriganville interval is predominantly medium gray to medium dark gray. The Mandata and Shriver-Ridgeley intervals are dark gray to grayish black; the sandy chert at the top weathers yellowish brown.

BEDDING: The New Creek-Corriganville and Shriver-Ridgeley intervals are mostly medium bedded, having beds ranging from 0.15 to 0.6 m (0.5 to 2 ft) in thickness; the Mandata interval is medium to thick bedded.

THICKNESS: The Old Port Formation is approximately 14 m (46 ft) thick in an excavated area above an abandoned quarry, 1.6 km (1.0 mile) northeast of Buckhorn (41°01'32"N/76°28'57"W). Apparently the Old Port thickens to the south and east within the report area, as thicknesses of 44 m (144 ft) and 30 to 45 m (100 to 150 ft) are reported at Grovania and Berwick, respectively (White, 1883¹; Inners, 1978).

Approximate thicknesses of the three main subdivisions of the Old Port in the southwestern part of the mapped area are (1) probable New Creek-Corriganville Members—2 m (7 ft); (2) probable Mandata Member—5 m (16 ft); and (3) probable Shriver-Ridgeley Members—7 m (23 ft). The “Grovania” sandstone is 0.6 to 0.75 m (2 to 2.5 ft) thick.

CONTACTS: The lower contact is abrupt, but conformable. The upper contact, as exposed at the abandoned quarry northeast of Buckhorn, is sharp and conformable, being marked by an abrupt change upward from

¹ White assigned most of the interval now included in the Old Port Formation to the “Stormville shale” and “Oriskany beds.”

sandy, fossiliferous chert to dark-gray clay shale of the overlying Onondaga Formation.

ORIGIN: The lower sandstone and calcarenite unit represents a transgressive shoreline deposit that accumulated above wave base in a shallow subtidal marine environment. The shale and chert in the remaining upper part of the Old Port were deposited in deeper, more offshore waters, although some shoaling is suggested by the sandy, fossiliferous chert at the very top of the formation.

BEST EXPOSURES: The only relatively complete exposures of the Old Port Formation within the mapped area are in an abandoned quarry and along the west side of Little Fishing Creek about 1.6 km (1 mi) northeast of Buckhorn (41°01'32"N/76°28'57"W and 41°01'33"N/76°28'52"W). The lower cherty calcarenites can be observed in an abandoned quarry about 245 m (800 ft) north of U. S. Route 11, 4.9 km (3.0 mi) east-northeast of the Bloomsburg town square (41°01'00"N/76°24'13"W). The "Grovania" sandstone crops out in a small quarry about 150 m (500 ft) northeast of Valley School, 1.4 km (0.9 mi) northwest of Rupert (40°58'58"N/76°29'28"W).

FIELD OCCURRENCE: Outcrop belts of the Old Port on the north and south limbs of the Berwick anticlinorium are mostly concealed by thick surficial deposits, but the formation does have topographic expression locally as a low ridge held up jointly with the Keyser and Tonoloway. On the north limb of the anticlinorium, the Old Port is commonly cut out at the surface by the Light Street fault. Few exposures exist within the mapped area, but float of chippy shale, blocky to rubbly chert, and leached silty limestone is easily recognizable in fields and shallow cuts.

Onondaga Formation

STRATIGRAPHIC COMMENT: In central Pennsylvania, the Onondaga Formation can nearly everywhere be conveniently subdivided into a lower shale member (Needmore) and an upper limestone member (Selinsgrove) (Willard, 1939; see also Inners, 1975). Although these two members are known to be present in the Berwick quadrangle immediately to the east of the report area (Inners, 1978), the Onondaga Formation in the vicinity of Bloomsburg appears to be dominantly shale. Because of widespread surficial cover and probable elimination of this interval by faulting on the north flank of the Berwick anticlinorium, the lithologic character of the upper Onondaga and the thickness of the entire unit must, to a great degree, be extrapolated from nearby areas.

LITHOLOGY: The lower part is noncalcareous to very calcareous, sparsely to moderately fossiliferous, slightly silty clay shale. The upper part is interbedded moderately fossiliferous, argillaceous calcisiltite and calcareous clay shale. Within this upper interval, calcisiltite beds are apparently absent in the southwestern part of the mapped area. Pyrite is common throughout, often occurring as rusty-weathered blebs up to 1 cm (0.4 in.) in diameter. Profuse horizontal trace-fossil trails cover many shale bedding planes. The fossil fauna of the Onondaga is dominated by the leptocoelid brachiopod *Pacificocoelia acutiplicata*.

COLOR: Medium gray to dark gray, weathering medium light gray, light olive gray, and yellowish gray.

BEDDING: The shales are medium to very thick bedded in the lower part, and are thin bedded in the upper part. The calcisiltites are mostly medium bedded.

THICKNESS: Approximately 15 m (50 ft) in the Bloomsburg area. The thickness of the formation increases northeastward to about 53 m (175 ft) at Berwick (Inners, 1978).

CONTACTS: The lower contact is sharp and conformable. Although the upper contact is not exposed in the report area, it is known to be conformable and interbedded through 1 m (3 ft) or less at nearby outcrops (Inners, 1975). The contact can generally be placed at the top of the uppermost medium-dark-gray, argillaceous calcisiltite of Selinsgrove aspect.

ORIGIN: The calcareous shales and argillaceous calcisiltites of the Onondaga Formation are probably moderately deep to moderately shallow subtidal marine deposits that accumulated under gradually shoaling conditions.

BEST EXPOSURES: The lower part of the Onondaga Formation is exposed in an abandoned borrow pit on the north side of U. S. Route 11, 1 km (0.6 mi) northwest of Rupert (40°59'05"N/76°28'59"W). Nearly the entire thickness of a seemingly attenuated Onondaga crops out above an abandoned quarry on the south side of Pa. Route 42, 1.6 km (1.0 mi) northeast of Buckhorn (41°01'32"N/76°28'57"W).

FIELD OCCURRENCE: West of Fishing Creek in the southwestern part of the mapped area, the Onondaga occupies a vague swale parallel to the poorly developed Old Port-Keyser-Tonoloway ridge. To the east, the outcrop of the formation on both flanks of the Berwick anticlinorium is completely covered by surficial deposits. Upon exposure to the atmosphere, the shales of the Onondaga rapidly weather to yellowish gray or light olive gray, and yield chippy, splintery, and papery fragments. However, the wide-

spread surficial cover precludes mapping of this float beyond the immediate vicinity of actual bedrock exposures.

Marcellus Formation

LITHOLOGY: The Marcellus Formation is predominantly carbonaceous, pyritic clay shale that becomes somewhat silty in the upper part. Near the top is a thin, discontinuous(?) interval of fetid, pyritic calcisiltite (probably equivalent to the Purcell Limestone Member of south-central Pennsylvania). The invertebrate fossil fauna is sparse, consisting chiefly of rhynchonellid brachiopods (*Leiorhynchus limitare*), cricoconarids (*Styliolina fissurella*), and small bivalves.

COLOR: Dark gray to grayish black. Shales weather light gray on the edges of papery fragments.

BEDDING: The shales are massive and homogeneous, exhibiting a well-developed bedding fissility. The calcisiltite is medium bedded.

THICKNESS: Approximately 105 m (350 ft) in the eastern part of the report area, thinning to 90 m (300 ft) or less in the western part. The calcisiltite unit is about 0.75 m (2.5 ft) thick.

CONTACTS: The lower contact is not exposed, but it is probably interbedded; it is defined as the top of the uppermost argillaceous limestone bed in the underlying Onondaga Formation. The Marcellus is gradational over an interval of about 10 m (33 ft) with the overlying Mahantango Formation; the upper contact is drawn at the change from grayish-black, very slightly silty clay shale to dark-gray, fossiliferous silty clay shale (Mahantango).

ORIGIN: The “black” shales of the Marcellus were deposited in a poorly oxygenated, probably relatively deep marine basin. Deposition of the Purcell(?) limestone took place during a short period of reduced terrigenous sediment input. Rare, small fossils in the Marcellus shales are probably the remains of pelagic, epiplanktonic organisms that lived in floating seaweed or other material in near-surface waters.

BEST EXPOSURES: No complete exposure of the Marcellus Formation is known within the report area. Portions of the formation are exposed: (1) along Legislative Route 19026 about 0.5 km (0.3 mi) northwest of Camp Creasy (includes Purcell(?) limestone) (41°01'58"N/76°27'07"W); (2) behind a warehouse on the north side of U. S. Route 11, about 1.8 km (1.1 mi) west of Rupert (40°58'46"N/76°29'46"W); and (3) on the north side of Pa. Route 42, 1.6 km (1.0 mi) northeast of Buckhorn (41°01'32"N/76°28'58"W).

FIELD OCCURRENCE: The Marcellus occupies broad valleys on the north and south flanks of the Berwick anticlinorium, but is almost completely covered by surficial deposits east of Bloomsburg and Light Street. It is locally cut out or thinned along the Light Street fault zone. Although the Marcellus breaks down into distinctive grayish-black, papery to chippy shale fragments, its float is nearly everywhere masked by surficial deposits. Exposures occur only in a few man-made cuts and excavations.

Mahantango Formation

STRATIGRAPHIC COMMENT: The Mahantango Formation in the report area can be divided for mapping purposes into a thick, unnamed lower member that is dominantly clay shale and claystone and a thin, upper Tully Member that consists mostly of argillaceous limestone.

LITHOLOGY: The lower member of the Mahantango Formation is predominantly noncalcareous to slightly calcareous, fossiliferous silty clay shale and claystone; a few siltstone beds occur in the upper part of this member. A 7-m- (23-ft-) thick interval of banded yellowish-gray and light-gray, calcareous argillite (similar to the overlying Tully Member) is developed in the middle part. Near the base is at least one 10-m- (33-ft-) thick interval of carbonaceous silty clay shale that resembles the Marcellus. The clay shales and claystones usually contain siderite nodules 2.5 to 10 cm (1 to 4 in.) in diameter that are flattened in the plane of bedding; where these nodules are abundant, they sometimes coalesce into nearly continuous, ropy bands. Interbedded with the typical non-limy shales and claystones of the lower member are numerous highly calcareous horizons, most of which are partly made up of fragmental marine fossils. The darker shales in the lower part are pyritic and are characterized by the occurrence of efflorescent masses of secondary sulfide minerals (e.g., pickeringite) on the surface of outcrops. The abundant fossil invertebrate fauna of the lower member includes numerous species of brachiopods, bivalves, trilobites, and corals, as well as a few cephalopods and bryozoans; crinoid columnals are common in most fossiliferous horizons. The darker shales bear a sparse fauna of diminutive brachiopods, bivalves, and cephalopods. In the area east of Briar Creek Lake a 1- to 3-m- (3- to 10-ft-) thick fossiliferous horizon is separately mappable about 230 m (750 ft) below the top of the member (Plate 1); recognition of this unit is based on its distinctive fauna dominated by *Athyris spiriferoides* (a spiriferid brachiopod), *Pleurodictyum styloporum* (a tabulate coral), and small rugose corals.

The Tully Member of the Mahantango is interbedded argillaceous calcisiltite and calcareous clay shale which is highly fossiliferous. Diagnostic fossils include *Spinatrypa spinosa* (a spine-bearing spiriferid brachiopod) and rugose corals.

COLOR: The lower member is mostly medium dark gray to dark gray, weathering yellowish gray and light olive gray; some grayish-black beds occur in the lower part. Siderite nodules are medium dark gray and weather yellowish brown.

The Tully Member is medium dark gray, weathering light gray and yellowish gray.

BEDDING: The silty clay shales and claystones of the lower member are medium to very thick bedded, homogeneous to crudely laminated, and often intensely bioturbated; the dark shales are fissile to subfissile. Strong cleavage development commonly obscures bedding on the flanks of the Berwick anticlinorium. Most siltstones are 5 cm (2 in.) or less in thickness and have fine cross laminae; a few calcareous, fossiliferous siltstones are up to 0.6 m (2 ft) thick. Limy, fossiliferous bands are generally less than 15 cm (6 in.) thick.

The Tully Member is thin to medium bedded; bedding is often poorly defined and recognized only as crude partings 2 to 30 cm (0.1 to 1 ft) apart. Cleavage is the most conspicuous foliation in some outcrops south of the Lackawanna synclinorium.

THICKNESS: Approximately 455 m (1,500 ft) in the eastern and northern parts of the mapped area, thinning to about 350 or 380 m (1,150 or 1,250 ft) in the southwestern part. The lower member ranges from 335 to 440 m (1,100 to 1,450 ft) in thickness. The thickness of the Tully Member varies from 15 to 18 m (50 to 60 ft).

CONTACTS: The lower contact of the Mahantango is conformable and gradational; the contact is drawn at the base of the lowest interval of dark-gray, fossiliferous, silty clay shale that occurs above typical Marcellus grayish-black clay shale. The upper contact is not exposed, but it is probably conformable and relatively sharp. The contact between the lower member and the Tully Member is conformable and gradational through an interval of 1 to 2 m (3 to 7 ft); the contact is placed at the base of the lowest extremely limy bed within this interval.

ORIGIN: The Mahantango Formation was deposited in moderately deep, well-oxygenated, nutrient-rich, open-marine waters off the distal margin of a large delta complex that occupied the area to the southeast. The sparse siltstones in the upper part may represent weak turbidity-flow deposits that originated on the slopes of this delta. Bottom conditions at the time of deposition of the Mahantango favored the proliferation of a diverse and abundant marine fauna, including filter feeders (corals, brachiopods, crinoids, and bryozoans), deposit feeders (bivalves and trilobites), and carnivores (gastropods and cephalopods). The *Athyris-Pleurodictyum*-rugose coral

horizon accumulated during a period of shoaling which permitted the growth of a coralline biostrome within the photic zone. A similar period of shoaling, which was also marked by a decrease in terrigenous influx, occurred at the end of Mahantango deposition and accounts for the widespread, richly fossiliferous Tully Member.

BEST EXPOSURES: A complete section of the lower member of the Mahantango Formation is not exposed within the report area. Good partial exposures occur along Legislative Route 19076 on the north side of Fishing Creek valley, 2 km (1.2 mi) west of Light Street (approximately $41^{\circ}02'10''\text{N}/76^{\circ}26'55''\text{W}$) and on the east side of Pa. Route 487, 0.5 km (0.3 mi) north of Light Street ($41^{\circ}02'33''\text{N}/76^{\circ}25'30''\text{W}$). The best exposure of the *Athyris-Pleurodictyum*-rugose coral horizon is in an abandoned borrow pit on the south side of Legislative Route 19042, 1.6 km (1.0 mi) west of Martzville ($41^{\circ}04'08''\text{N}/76^{\circ}17'03''\text{W}$). The Tully Member crops out: (1) at the north end of the section on Pa. Route 487 near Light Street; (2) on the east side of North Centre Township Route 656, 3.2 km (2.0 mi) west of Fowlersville ($41^{\circ}03'34''\text{N}/76^{\circ}22'05''\text{W}$); and (3) along Greenwood Township Routes 526 and 524, about 1.6 km (1.0 mi) northwest of Welliversville ($41^{\circ}06'17''\text{N}/76^{\circ}29'33''\text{W}$ and $41^{\circ}06'19''\text{N}/76^{\circ}29'43''\text{W}$).

FIELD OCCURRENCE: Typically, the Mahantango underlies relatively narrow belts of low, knobby hills in front of steep escarpments developed on the lower part of the Trimmers Rock Formation; often, however, streams have eroded broad strike-valleys along the outcrop belt of the Mahantango (e.g., the Susquehanna River, West Branch of Briar Creek, and Mud Run). Splintery and chippy clay shale float of the lower member and chippy to platy, leached limestone float of the Tully Member are easily recognizable where the Mahantango outcrop has not been covered by surficial deposits. Colluvial, fragmental material from the lower member blankets most moderate to steep slopes. Both members are widely exposed in borrow pits and highway and railroad cuts. Natural exposures are quite common in steep ravines, particularly those on the south side of the Susquehanna River southwest of Mifflinville.

Harrell Formation

LITHOLOGY: Clay shale, somewhat silty near the top. Thin intervals of silt-clay laminite and lenticular beds of siltstone are intercalated with the upper silty clay shales.

COLOR: Shales are dark gray to grayish black and weather medium to light gray, often with a bleached white or light-brown edge on chippy frag-

ments. Silty laminae and beds are medium dark gray, weathering light olive gray. Fracture surfaces are often coated with thin scales of orange-brown (“rusty”) limonite derived from the weathering of pyrite (iron sulfide) that is finely disseminated through the rock.

BEDDING: Shales are massive, homogeneous, and fissile. The silty layers are laminated to thin bedded (up to about 2 cm, or 0.8 in., thick) and commonly exhibit fine cross laminations.

THICKNESS: The average thickness is approximately 36 m (120 ft). Measurement of two incompletely exposed sections suggests a thickness of 43 m (140 ft) along Legislative Route 19020, about 1.5 km (0.9 mi) southwest of Mifflinville (41°01'16"N/76°19'14"W), and a thickness of 30 m (100 ft) along Legislative Route 19029 about 1.0 km (0.6 mi) north of Welliversville (41°06'25"N/76°28'36"W).

CONTACTS: The lower contact was not observed within the mapped area, but it is probably conformable and relatively sharp. The upper contact is conformable and gradational; it is defined by an increase in the silt content of the shales and by the first appearance of siltstone beds 5 cm (2 in.) or more in thickness.

ORIGIN: The Harrell shales represent clays and fine silts that were deposited from suspension in a deep, poorly oxygenated marine basin seaward of the prograding Catskill delta complex. The silt laminae and thin, cross-laminated siltstone beds in the upper part mark the initial influx of the turbidites that characterize much of Trimmers Rock deposition.

BEST EXPOSURES: The formation is exposed: (1) in abandoned pits of the Alliance Clay Products Company about 2.5 km (1.5 mi) east-southeast of Mifflinville (41°01'48"N/76°16'42"W) (see “Mineral Resources” section), and (2) on the east side of Legislative Route 19029 about 1.0 km (0.6 mi) north of Welliversville.

FIELD OCCURRENCE: The Harrell crops out in narrow belts on both limbs of the Berwick anticlinorium and on the south limb of the Milton anticlinorium, generally forming a distinct swale between the low, rounded hills underlain by the Tully Member of the Mahantango Formation and the steep escarpment developed on the lower part of the Trimmers Rock Formation. The chippy and splintery float of the Harrell is generally masked by coarser colluvium from the overlying Trimmers Rock Formation. Exposures are mostly in artificial cuts, but a few natural outcrops occur along deeply incised streams; e.g., in the ravines on the south side of the Susquehanna River about 4.5 km (2.8 mi) west-southwest of Mifflinville.

Trimmers Rock Formation

LITHOLOGY: Interbedded siltstone, very fine grained sandstone, and silt shale. The formation contains some fine- to medium-grained sandstone (middle and upper parts) and considerable silty clay shale (especially in the lower part). The dominant siltstones and finer grained sandstones are generally argillaceous and occasionally siliceous; they often exhibit graded bedding, fine rippling, and sole markings, and rarely contain concentrations of discoidal, light-olive-gray claystone clasts at the bases of beds. Calcareous, bioskeletal lenses 2 to 10 cm (0.8 to 4 in.) thick (rarely to 38 cm, or 15 in.) are common in the siltstones and sandstones of the middle and upper portions of the Trimmers Rock. Beds in the uppermost part of the middle and southern outcrop belts are intensely bioturbated; the largest burrow structures, approximately 2.5 cm (1 in.) in diameter and normal to bedding, occur in thick crossbedded sandstone. About 15 to 25 m (50 to 80 ft) below the top of the formation in the central outcrop belt and at the top of the formation in the northern belt is a 0.5- to 1-m- (1.6- to 3-ft-) thick, siliceous, coarsening-upward, medium-grained to conglomeratic sandstone that contains flat, rounded quartz pebbles 1 cm (0.4 in.) or less in diameter. Marine invertebrate fossils are profuse in the upper 600 m (1,968 ft) of the Trimmers Rock, generally occurring in bioskeletal lenses. Relatively low diversity characterizes the assemblages. Most abundant are brachiopods, crinoids (columnals), bryozoans, and bivalves. Approximately 120 to 150 m (400 to 500 ft) below the top of the formation is a readily traceable, 15- to 23-m (50- to 75-ft) interval of highly fossiliferous, argillaceous siltstone and silty clay shale that contains a distinctive fauna of rhynchonellid, productid, and spiriferid brachiopods, bivalves, and large cephalopods—the Stony Brook beds of I. C. White (1883) (Inners, 1981).

COLOR: Mostly medium gray and medium dark gray, weathering olive gray. Silty clay shales are medium dark gray to dark gray.

BEDDING: The siltstones are thin to medium bedded; some are finely cross laminated. Siltstone beds commonly have sharp upper and lower boundaries, especially in the lower part of the formation. Sandstones are medium to thick bedded, and are locally crossbedded near the top of the formation. The silt shales are medium to thick bedded, are often rippled, and may contain trains of small, isolated, very fine grained sandstone lenses (starved ripples). The silty clay shales are fissile to laminated and occur in beds 2 to 60 cm (1 to 24 in.) thick; silt laminae are common. Both siltstone and sandstone beds in the middle and upper part of the formation frequently exhibit load casts and ball-and-pillow structures.

THICKNESS: Approximately 760 m (2,500 ft).

CONTACTS: The lower contact is conformable and gradational; it is placed at the base of the lowest 5-cm- (2-in.-) thick siltstone in an interbedded sequence. The upper contact is conformable and sharp; it occurs at the base of the lowest red, subaerially deposited claystone of the Catskill Formation (Irish Valley Member) in the middle and southern outcrop belts, and at the top of a prominent conglomeratic sandstone in the northern outcrop belt, where the overlying Irish Valley Member is dominantly marine.

ORIGIN: The Trimmers Rock Formation includes a variety of marine sedimentary deposits that accumulated under gradually shoaling conditions seaward of the prograding Catskill delta complex. The silty clay shales and graded siltstones in the lower part of the formation are mixed prodelta muds and distal turbidites. The highly fossiliferous middle and upper portions represent mainly proximal-turbidite and nearshore shallow-marine-shelf deposition. The intensely bioturbated sandstones and siltstones in the uppermost 60 m (200 ft) of the middle and southern outcrop belts are of very shallow subtidal or even intertidal origin. Crossbedded, locally conglomeratic sandstones in the same interval and at the top of the formation in the northern outcrop belt may be offshore-bar deposits.

BEST EXPOSURES: Nearly complete sections of the Trimmers Rock Formation are exposed: (1) along Pa. Route 42 south of Rupert (includes upper contact) ($40^{\circ}58'32''\text{N}/76^{\circ}28'23''\text{W}$ to $40^{\circ}58'06''\text{N}/76^{\circ}28'22''\text{W}$); (2) along Pa. Route 42 on the west side of Little Fishing Creek valley about 2.4 km (1.5 mi) northeast of Buckhorn (includes both lower and upper contacts) ($41^{\circ}01'50''\text{N}/76^{\circ}28'52''\text{W}$ to $41^{\circ}02'20''\text{N}/76^{\circ}29'12''\text{W}$); and (3) along Legislative Route 19024 about 3.5 km (2.2 mi) east of Mifflinville ($41^{\circ}02'05''\text{N}/76^{\circ}15'25''\text{W}$ to $41^{\circ}01'32''\text{N}/76^{\circ}15'29''\text{W}$). Another excellent section, exposing both the upper and lower contacts, lies just outside the report area along the Conrail tracks on the south side of the Susquehanna River opposite Bloomsburg (Frakes, 1967).

The Stony Brook beds of White (1883) crop out at numerous localities, one of the most accessible of which is in a borrow pit at a sharp bend in Legislative Route 19022, about 3.6 km (2.2 mi) southwest of Mifflinville ($41^{\circ}00'30''\text{N}/76^{\circ}20'17''\text{W}$).

FIELD OCCURRENCE: Forms prominent upland areas, the margins of which are steep escarpments that stand 75 to 150 m (250 to 500 ft) above the adjacent terrain (e.g., River Hill and Summer Hill). The olive-gray, chippy, platy, and slabby fragments formed by the disintegration and weathering of the various Trimmers Rock lithologies are abundant in cleared fields and shallow excavations; on moderate to steep slopes similar material forms thick colluvial deposits. Many natural outcrops occur along stream banks and in steep ravines. The formation is also widely exposed in borrow pits, abandoned quarries, and highway and railroad cuts.

Catskill Formation

The Catskill Formation in the Bloomsburg-Mifflinville area is divided from the base upward into the Irish Valley, Sherman Creek, and Duncannon Members. These mapped subdivisions are based on separation of the various depositional environments that are represented in the stratigraphic succession and result from the northwestward progradation of a major sub-aerial delta complex. The depositional environments of strata in this complex are interpreted to range from shallow marine and coastal fringe in the Irish Valley Member to distal alluvial plain in the Duncannon Member.

The total thickness of the Catskill Formation in the report area is approximately 1,700 m (5,600 ft).

Irish Valley Member

LITHOLOGY: The lower part is mostly interbedded gray and olive, fossiliferous, silty clay shale, siltstone, and sandstone; at the base in the middle and southern outcrop belts is a 2- to 4-m- (7- to 13-ft-) thick interval of red, rootworked silty claystone. The upper part of the Irish Valley comprises cyclic repetitions of nonred, fossiliferous sandstones, siltstones, and silty clay shales, and red sandstones, siltstones, and claystones described as “Irish Valley motifs” by Walker and Harms (1971). (An Irish Valley motif is a vertical sequence of rock strata consisting, in ascending order, of a sharp-based, bioturbated, marine sandstone, olive-gray marine siltstones and shales, red nonmarine siltstones, and red nonmarine silty claystones containing root traces, mud cracks, and calcareous nodules.) Motifs in the report area are typically 3 to 12 m (10 to 40 ft) thick, but range up to 30 m (100 ft).

The silty clay shales are fissile to subfissile and commonly fossiliferous. The siltstones are typically ripple bedded in the lower part of the member and bioturbated in the upper part. The sandstones are mostly very fine to fine grained and micaceous; in some cases, they are medium grained to finely conglomeratic and quartzitic. The sandstones contain lenticular bioskeletal lenses 3 to 10 cm (1.2 to 4 in.) thick, and bioturbation is locally intense. Some calcareous breccia horizons up to 10 cm (4 in.) thick are present, and numerous grayish-red and olive-gray claystone clasts occur in some of the sandstones of the upper, cyclic portion. The maximum thickness of individual sandstone units is about 8 m (26 ft). The claystones are massive and hackly; fossil root traces and mud cracks are usually evident. Invertebrate fossils occur in fragmental accumulations and as individuals scattered throughout sandstone or silty clay shale beds; the most common are crinoid columnals, brachiopods (especially spiriferids), and bivalves. Carbonized fossil wood fragments are relatively common in the motif sandstones; generally this plant debris forms distinct concentrations, some of which contain spiriferid brachiopods as well.

COLOR: Silty clay shales are light olive gray, weathering light orangish brown. Siltstones are mostly light olive gray in the lower part of the Irish Valley, and are light olive gray and grayish red in the upper part. Sandstones are predominantly medium light gray to light olive gray, occasionally pale purplish gray, purplish red, and grayish red in the upper part. Silty claystones are grayish red.

BEDDING: Silty clay shale beds range in thickness from 2 cm to 1.2 m (1 in. to 4 ft). Siltstones are thin to medium bedded. Sandstones are thin to thick bedded; they are commonly lenticular and cross laminated in the lower part, and are strongly crossbedded and occasionally flaggy in the upper part. Some sandstone bedding planes exhibit ripple markings or parting lineations. Sandstones in motifs are often intensely bioturbated. Load casts (Figure 6), and ball-and-pillow and slump structures are typical soft-sediment deformation structures occurring in many sandstone beds in the lower part of the member. The silty claystones are thick to very thick bedded.



Figure 6. Load casts in gray sandstone near the base of the Irish Valley Member of the Catskill Formation, on the east side of Legislative Route 19067, 2.7 km (1.7 mi) south of Rohrsburg ($41^{\circ}06'28''\text{N}/76^{\circ}25'01''\text{W}$). The sandstone is overlain and underlain by platy, olive-gray clay shale. The hammer is 28 cm (11 in.) long.

THICKNESS: 550 to 600 m (1,800 to 2,000 ft). The lower, dominantly marine portion is 200 to 225 m (650 to 750 ft) thick, and the upper cyclic portion is 350 to 375 m (1,150 to 1,250 ft) thick.

CONTACTS: The lower contact is sharp and conformable, and is marked by a basal grayish-red, rootworked claystone in the middle and southern outcrop belts, and by the top of the upper conglomeratic sandstone of the Trimmers Rock Formation in the northern belt. (The red rootworked claystone is absent in the northern outcrop belt, but lithologies identical to those in the lower Irish Valley of the southern part of the mapped area occur directly above the specified conglomeratic sandstone of this northern belt.) The upper contact is conformable and gradational and is characterized by a change from the alternating red and nonred, nonmarine-marine cycles of the upper Irish Valley to the thick, dominantly red, nonmarine sequence of the basal Sherman Creek.

ORIGIN: The lower portion of the Irish Valley represents dominantly shallow marine slope and shelf deposition that followed a short period of delta progradation (grayish-red claystone interval) in the central and southern part of the report area. Load casts and ball-and-pillow structures in these lower beds resulted from the vertical settling of heavier sand beds into underlying soft, muddy sediments. Lateral movement of these previously loaded beds took place on locally unstable slopes to form the slump structures. The upper cyclic portion of the Irish Valley accumulated along the oscillating coastal fringe of the Catskill delta complex (Walker and Harms, 1971).

BEST EXPOSURES: The Irish Valley is almost completely exposed along Pa. Route 42, beginning just north of the intersection with Montour Township Route 435 and extending to the parking area at Indian Rock (40°58'06"N/76°28'22"W to 40°57'40"N/76°28'12"W) (Walker, 1972). Good partial exposures are located: (1) along an abandoned railroad grade on the east side of Fishing Creek, 1.4 km (0.9 mi) north-northeast of Forks (41°07'09"N/76°21'18"W); (2) along Legislative Route 19058 immediately north of Mordansville (41°04'12"N/76°29'58"W); (3) along Pa. Route 487 about 2.1 km (1.3 mi) north of Light Street (41°03'28"N/76°25'46"W); and (4) along the westbound lane of Interstate Route 80 about 2.4 km (1.5 mi) south-southeast of Mifflinville (41°00'50"N/76°18'04"W and 41°00'40"N/76°17'43"W).

FIELD OCCURRENCE: Underlies moderately dissected, rolling terrain in the southeastern and central to northern part of the report area. The most abundant float that is derived from the Irish Valley consists of a mixture of light-olive-gray to light-orangish-brown, chippy clay shale and light-olive-

gray to medium-light-gray, occasionally fossiliferous, slabby and platy sandstone. In terrain underlain by the upper part of the member, grayish-red to light-olive-gray, flaggy sandstone and grayish-red, chippy to platy claystone and siltstone form a large percentage of the residual material evident in fields and shallow cuts. The Irish Valley Member is widely exposed in various types of artificial excavations. Small natural exposures occur along some deeply incised streams, such as Little Fishing Creek, Fishing Creek, and the East Branch of Briar Creek.

Sherman Creek Member

LITHOLOGY: Predominantly interbedded red claystones, siltstones, and sandstones, but also contains gray sandstones that form basal portions of many fining-upward cycles. All red lithologies are commonly calcareous and develop distinctive pitted surfaces on weathering. The claystones are generally silty and always show evidence of rootworking, desiccation, and bioturbation. The siltstones range from siliceous and rippled to argillaceous and massive; many siltstones contain abundant root traces, mud cracks, and burrows. Red sandstones are very fine to fine grained and micaceous. Gray sandstones, in units up to 12 m (39 ft) thick, are fine to medium grained, rarely coarse grained, micaceous, and occasionally rootworked where gray color gives way to red in the vertical sequence. Many of the gray sandstones contain lenses of calcareous breccia consisting of claystone clasts, carbonate nodules, and fish bones. Associated with the breccia lenses are concentrations of carbonized wood that may exhibit copper-uranium mineralization (see “Mineral Resources” section). Little erosional relief is evident at the base of the cycles.

The lower half of the Sherman Creek Member also includes several mappable intervals of interbedded fossiliferous, gray and olive-gray, fine-grained sandstone, siltstone, sand-silt laminite, and silty clay shale that are similar to the thick marine portions of some Irish Valley motifs. The thickness of these marine horizons ranges from less than 3 m (10 ft) to about 35 m (120 ft). In these marine horizons, the fossils—the most abundant of which are brachiopods (spiriferids, rhynchonellids, and strophomenids), small bivalves, and crinoid columnals—usually occur in bioskeletal lenses to 20 cm (8 in.) thick. Some invertebrate fossil beds are also rich in carbonized plant debris.

COLOR: Claystones in the Sherman Creek are grayish red. Siltstones are also grayish red, except in the marine horizons, where they are medium gray to light olive gray. Very fine grained and fine-grained sandstones are mostly grayish red, but some are pale red, grayish red purple, and, especially in marine horizons, medium gray to light olive gray. Medium- and coarse-grained sandstones are medium gray to greenish gray. Silty clay shales and laminites in marine horizons are mostly light olive gray.

BEDDING: Claystones occur as structureless beds, generally 0.3 to 1.5 m (1 to 5 ft) thick. Red siltstones are thin to medium bedded, commonly rippled. Red sandstones are thin to thick bedded, planar bedded, rippled, or crossbedded. Gray sandstones are mostly medium to thick bedded (some thin beds occur in marine horizons), and planar to strongly crossbedded; crossbed sets are trough shaped and range from 15 cm to 1 m (0.5 to 3 ft) in thickness; some beds are flaggy and exhibit well-developed parting-step lineations. In marine horizons, silty clay shales are thin to medium bedded and fissile; the laminites and siltstones are medium to thick bedded and grade into silty clay shales that have discontinuous (starved) ripples composed of silt or very fine sand.

THICKNESS: Approximately 760 m (2,500 ft).

CONTACTS: The lower contact is conformable and gradational; it is placed at the base of the thick, dominantly red interval that occurs above the uppermost red-nonred, nonmarine-marine cycle of the upper Irish Valley. The upper contact is not exposed within the report area, but it is probably conformable and gradational.

ORIGIN: The Sherman Creek Member preserves a variety of deltaic depositional environments. The thick red, calcareous intervals are the deposits of a low-energy, coastal (delta-plain) fluvial system (Epstein and others, 1974). The fining-upward cycles represent deposition by higher energy, meandering rivers that had distinct channels (gray sandstones), levees (red siltstone and very fine grained sandstones) and floodplains (red claystones). Coarser sandstones at the base of the cycles probably owe their gray color to the fact that they were originally more permeable than the surrounding sediments; they thus served as conduits for reducing groundwater under the paleohydrologic regime that existed shortly after their deposition. The gray, fossiliferous horizons in the lower half of the member resulted from periodic marine transgressions into broad embayments along the fringe of the delta complex. These interruptions in deltaic progradation may have been caused by a combination of distributary switching and compaction of delta-plain muds.

BEST EXPOSURES: Although the Sherman Creek Member is widely exposed in the report area, even the longest sections reveal less than half its total thickness. The most complete exposures are the following: (1) at the village of Forks (41°06'46"N/76°21'54"W to 41°06'24"N/76°21'45"W); (2) west and southwest of Orangeville along Pa. Route 487 and on the west side of the "umlauferg" (41°03'36"N/76°25'49"W to 41°04'33"N/76°25'38"W); and (3) along Pa. Route 42 south of Mordansville from just south of Mom's Place northward to near the axis of the Lackawanna synclorium (41°02'54"N/76°29'23"W to 41°03'25"N/76°29'35"W).

Good exposures of the marine horizons are at Twin Bridges Park, 0.5 km (0.3 mi) southeast of Forks (41°06'26"N/76°21'25"W), and along an abandoned railroad grade 0.5 km (0.3 mi) southeast of Mordansville (41°03'56"N/76°29'39"W).

FIELD OCCURRENCE: The Sherman Creek underlies undulating, deeply dissected terrain in the southeastern, central, and north-central portions of the mapped area. Float of chippy to platy, grayish-red, pitted siltstone and very fine grained sandstone and flaggy to blocky, light-olive-gray to medium-gray sandstone partly covers the ground surface in areas underlain by nonmarine portions of the member. Chippy, olive-gray clay shale and slabby, fossiliferous sandstone float marks the outcrop trace of marine horizons. Natural exposures are common along steep valley walls and in deep ravines. The Sherman Creek is also exposed in many highway and railroad cuts and in a few quarries, one of which is currently active (see "Mineral Resources" section).

Duncannon Member

LITHOLOGY: Interbedded gray and red sandstones, red siltstones, and red silty claystones arranged in repetitive, asymmetrical, fining-upward cycles that are generally 10 to 20 m (33 to 66 ft) thick. Gray sandstones occur at the bases of cycles and are mostly fine to medium grained, but some are coarse grained. Red sandstones are very fine to fine grained and micaceous. The siltstones are micaceous and often rippled. The claystones are mud cracked and rootworked; they also commonly exhibit irregular, slickensided surfaces oriented obliquely to bedding. The cycles typically have sharp erosional bases; lithologic boundaries within cycles are gradational. Olive-gray and grayish-red claystone clasts and carbonized wood fragments are commonly concentrated in erosional scours at the bases of gray sandstones of some cycles. A few thin, pebbly quartz conglomerate bands and lenses occur in sandstones near the top of the member.

COLOR: The sandstones are light olive gray, greenish gray, and grayish red; they are banded purplish gray and light olive gray in the upper part. Siltstones and silty claystones are grayish red.

BEDDING: The gray sandstones of the Duncannon are mostly medium to thick bedded and strongly crossbedded; crossbeds are generally wedge- or trough-shaped sets ranging up to 1 m (3 ft) thick (Figure 7). Red sandstones and siltstones are medium to thick bedded and planar bedded to rippled. The silty claystones are massive, the bedding having been destroyed by rootworking and repeated desiccation.

THICKNESS: Approximately 335 m (1,100 ft).



Figure 7. Strongly trough crossbedded, gray quartzitic sandstone of the Duncannon Member of the Catskill Formation, on the south side (near the crest) of Knob Mountain, 2.3 km (1.4 mi) east-northeast of Orangeville ($41^{\circ}05'10''\text{N}/76^{\circ}23'20''\text{W}$). Bedding dips northwest on the south limb of the Lackawanna synclinorium. The hammer is 28 cm (11 in.) long.

CONTACTS: Both the upper and lower contacts are concealed by stony and boulder colluvium on the mountain slopes. The lower contact is presumed to be within a gradational zone; the upper contact is sharp and probably disconformable.

ORIGIN: The fining-upward cycles of the Duncannon Member were deposited by meandering rivers on the proximal (landward) portion of the Catskill delta complex. The basal gray sandstones are channel and point-bar deposits; the medial fine sandstones and siltstones represent levee deposits; the rootworked claystones at the top are overbank, flood-basin deposits.

BEST EXPOSURE: The Duncannon crops out along Legislative Route 894 on the north (scarp) slope of Huntington Mountain, 4.0 km (2.5 mi) north-northwest of Summer Hill (41°07'25"N/76°16'51"W).

FIELD OCCURRENCE: The member underlies the steep scarp slopes of Nescopeck, Knob, Lee, and Huntington Mountains and the promontory at the nose of Knob Mountain above Orangeville. The rubbly, slabby, and blocky debris derived from fragmentation of the Duncannon sandstones forms a blanket of stony colluvium that extends downslope to the base of the mountains. Natural outcrops of gray sandstone are fairly common around the rim of Knob Mountain within 4 km (2.5 mi) of Orangeville. The red siltstones and claystones are exposed only in artificial cuts; they typically break down into chippy, hackly, and platy fragments.

MISSISSIPPIAN SYSTEM

Pocono Formation

STRATIGRAPHIC COMMENT: In the southwestern part of the Lackawanna basin within the mapped area, the red beds of the Catskill Formation are succeeded directly by quartzitic sandstones and conglomerates of the Pocono Formation. In surrounding areas, however (Figure 8), thick transitional sequences, consisting of conglomeratic sandstones (with local pebbly mudstones) in the east and south (Spechty Kopf Formation) and greenish flaggy sandstones (with some red claystone intervals) in the north (Huntley Mountain Formation), are developed (Sevon, 1969; Inners, 1978; Edmunds and others, 1979). The Spechty Kopf and Huntley Mountain are considered to span the Devonian-Mississippian systemic boundary. The absence of this transitional interval in the Bloomsburg and Mifflinville quadrangles may be due to a variety of factors, including nondeposition, erosional truncation, facies change, or a combination of these. The occurrence of purplish-gray and medium-gray banded sandstones in the Duncannon Member similar to those in the lower part of the Spechty Kopf Formation on Nescopeck Mountain (p. 36; Inners, 1978) suggests that the upper part of the Duncannon on Lee, Huntington, and Knob Mountains may be in part equivalent to the Spechty Kopf. If such is the case, the distinctive conglomeratic, in part braided-river deposits of the Spechty Kopf would appear to be thinning and grading northwestward into the meandering-river deposits of the Duncannon.

LITHOLOGY: The Pocono Formation consists of medium-grained to conglomeratic quartz sandstone and pebbly quartz conglomerate having subordinate carbonaceous silty claystone, silt-clay laminite, and sand-silt laminite. Quartz pebbles in the conglomeratic beds are rounded to subrounded and mostly 0.5 to 1 cm (0.2 to 0.4 in.) in diameter, ranging to 3 cm (1.2 in.) in the lower part. Very light gray claystone galls to 6 cm (2.4 in.) and some

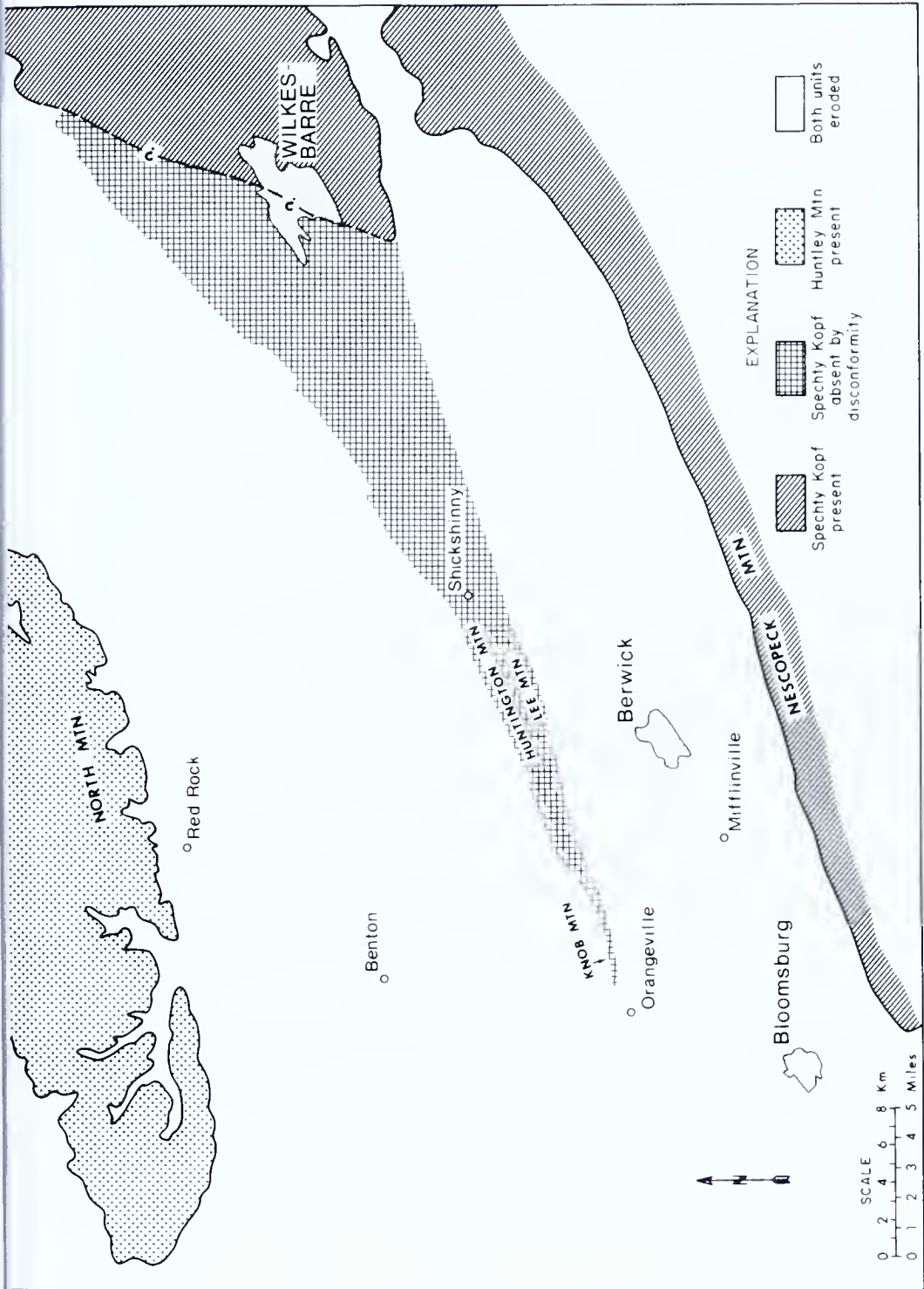


Figure 8. Areal extent of the Spechty Kopf and Huntley Mountain Formations (Mississippian-Devonian) in the vicinity of the report area (after Berg and others, 1980).

yellowish-brown-weathered limonite nodules of similar size are also present. The sandstones are locally micaceous, having bedding planes that are covered by golden-brown mica flakes 0.5 to 2 mm in diameter. Carbonized fossil plant fragments and limonite-stained fossil stem casts occur in some sandstone beds; carbonized fossil plant debris is also common in the claystones and laminites.

COLOR: The sandstones and conglomerate are mostly medium light gray and weather grayish orange pink, light olive gray, and dark yellowish gray. About 60 m (200 ft) above the base of the formation is a distinctive horizon of white, friable, highly quartzose sandstone and conglomerate. The claystones and laminites are dominantly medium dark gray to grayish black.

BEDDING: The sandstone and conglomerate are predominantly medium to thick bedded, locally thin bedded, and strongly cross bedded in wedge-shaped sets (of high-angle planar and curved cross-strata) 8 cm to 1.0 m (0.26 to 3.3 ft) thick. Partings are generally wavy to ropy; beds are not usually continuous across the length of most outcrops. True conglomerate beds range from 10 to 75 cm (0.3 to 2.5 ft) thick. The claystones and laminites are thin to medium bedded, generally occurring in lenticular units less than 2 m (7 ft) thick.

THICKNESS: 180 to 200 m (600 to 650 ft).

CONTACTS: Although not exposed within the mapped area, the lower contact of the Pocono is probably sharp and possibly disconformable. The upper contact is also concealed, but is probably conformable and within a gradational interval.

ORIGIN: The Pocono Formation represents predominantly braided-river deposition. Claystone and laminite beds probably formed in shallow lakes and ponds that periodically occupied abandoned channels.

BEST EXPOSURES: The Pocono is well exposed: (1) in cuts along Legislative Route 19040 at the crest of Lee Mountain and on the dip slope of Huntington Mountain, 2.9 km (1.8 mi) and 4.0 km (2.5 mi), respectively, northwest of Summer Hill (41°06'36"N/76°16'51"W and 41°07'22"N/76°16'38"W); (2) in the deep glen on Lee Mountain at the head of one of the main branches of the West Branch of Briar Creek (41°06'21"N/76°18'39"W); and (3) in natural cliffs on the crest of Knob Mountain about 1.8 km (1.1 mi) south-southeast of Forks (41°05'38"N/76°21'09"W).

FIELD OCCURRENCE: Forms the crests and dip slopes of Huntington and Lee Mountains and much of the Knob Mountain crest to a point about

1.6 km (1 mi) east-northeast of Orangeville. Due to its extreme resistance to erosion, the Pocono caps mountains of high relief having moderate to steep slopes. The quartzitic sandstones and conglomerates break along widely spaced joints and more closely spaced bedding planes to form blocky, rubbly, and slabby fragments. Natural ledges are frequently exposed along the mountain summits; they nearly always show evidence of intense frost riving.

Mauch Chunk Formation

LITHOLOGY: The Mauch Chunk Formation is not exposed in this report area, but probably consists mostly of interbedded silty claystone, siltstone, and very fine to medium-grained micaceous sandstone. The basal 30 m (100 ft) may contain a concentration of slightly calcareous sandstone beds (Wells, 1973).

COLOR: The dominant color of all Mauch Chunk lithologies is grayish red.

BEDDING: The claystones and siltstones are mostly medium to very thick bedded; the sandstones are medium to thick bedded and, in many places, planar crossbedded.

THICKNESS: Presumably only the lower 150 m (500 ft) of the Mauch Chunk is preserved in the mapped area. The total thickness of the formation in the vicinity of Shickshinny, Luzerne County, 9.4 km (5.8 mi) to the east-northeast, is probably 305 to 370 m (1,000 to 1,200 ft) (White, 1883).

CONTACTS: The nature of the contact with the underlying Pocono Formation is unknown, but it is probably within a transition from tightly cemented, quartzitic sandstones in the upper Pocono to interbedded poorly cemented, argillaceous sandstones and red claystones in the lower Mauch Chunk.

ORIGIN: The red beds of the Mauch Chunk are probably alluvial-plain deposits. The fine-grained sandstones may represent channel fills of low-energy streams, whereas the siltstones and claystones are most likely mixed levee and overbank accumulations.

BEST EXPOSURES: No exposures of the Mauch Chunk are known within the report area. The nearest exposures are cuts along U. S. Route 11, 0.6 km (0.4 mi) south of Shickshinny (41°08'39"N/76°08'56"W, Shickshinny quadrangle, northeast of the report area) and on the steep bluffs that line the south side of the Susquehanna River 1.6 km (1.0 mi) northeast of Shickshinny (41°09'33"N/76°08'09"W) (Wells, 1973).

FIELD OCCURRENCE: The Mauch Chunk Formation occupies the cove valley between Huntington and Lee Mountain, where it is completely covered by boulder colluvium and Olean glacial drift. That the Mauch Chunk does occur within this portion of the report area is suggested by: (1) the existence of a narrow valley, presumably developed on rocks having low resistance to weathering, along the axis of the Lackawanna synclorium, and (2) the occurrence of red beds in water wells in the northwest corner of the adjacent Berwick quadrangle (Inners, 1978).

QUATERNARY SYSTEM

Pleistocene

Muncy Till

GENERAL COMMENT: Wells and Bucek (1980) named the Muncy Till from exposures along new U. S. Route 220 between Montoursville and Muncy, Lycoming County. Because the deep weathering profile developed on the till in the type area is similar to the Sangamonian soil profile characteristic of Illinoian tills in the mid-continent region, the Muncy Till is assigned an Illinoian age.

LITHOLOGY: The Muncy Till is a nonstratified, unsorted mixture of clay, silt, sand, pebbles, cobbles, and boulders (Figure 9) that may locally contain lenses of crudely stratified sand and gravel. Typical Muncy Till consists of 15 to 20 percent clay, 20 percent silt, 25 percent sand, and 35 percent pebble-sized and larger clasts, but till in some areas may contain 30 percent clay (Figure 10). Many pebbles and cobbles have slippery clay “skins.” The color of the till is typically reddish or yellowish orange; reddish brown hues are characteristic where the till overlies red bedrock. Pebbles, cobbles, and boulders in the Muncy Till are mostly subangular to well rounded, but considerable local differences exist in the degree of clast rounding. Deposits on low uplands and near major stream courses usually contain abundant rounded, erratic clasts, whereas those on upland interfluvies have a greater percentage of angular to subangular, locally derived material. Some subrounded to rounded siltstone and very fine grained sandstone clasts bear distinct, fine striations. Erratic boulders larger than 1.0 m (3.3 ft) are fairly common, particularly in the south-central part of the mapped area; the overwhelming majority of these boulders are white quartzite or quartzitic conglomerate of Pocono or Pottsville derivation. A 4 x 2 x 2 m (13 x 7 x 7 ft) conglomerate boulder that lies at the head of a deep ravine, 5.1 km (3.2 mi) west-southwest of Mifflinville (41°00'35"N/76°21'57"W), is probably the largest in the area.

Pebble-sized and larger clasts in the Muncy Till are mostly moderately to deeply weathered. Gray or olive-gray shale, siltstone, and fine-grained sandstone clasts are often thoroughly decomposed and can easily be broken



Figure 9. Bouldery, reddish-brown Muncy Till (Qmt) overlying grayish-red claystone of the Bloomensburg Formation (Sb) on the road to Michaels Meadow Campground, 1.6 km (1.0 mi) north of Almedia ($41^{\circ}01'45''\text{N}/76^{\circ}23'26''\text{W}$). Striated pebbles and cobbles are relatively common at this locality.

with a single blow of a hammer. Conglomerate and coarse-grained sandstone clasts are usually friable, but some highly quartzitic clasts are hard and unweathered. Many pebbles and cobbles exhibit yellowish-brown, limonitic weathering rinds up to 1 cm (0.4 in.) thick, and others are rubified (i.e., altered to orangish red on the surface and in the interior). Grayish-red sandstones and claystones are commonly less deeply weathered than nonred clasts and may have only faint weathering rinds.

In areas of poor drainage, the Muncy Till takes on a mottled yellowish-gray and medium-light-gray coloration due to a reduction of iron oxides in the fine matrix from the ferric to the ferrous state (gleization). Weathering prisms may extend at least 2 m (7 ft) below the ground surface in such gleized till.

THICKNESS: Ranges from less than 1 m (3 ft) to at least 8 m (26 ft), but probably averages about 3 m (10 ft).

CONTACTS: The basal contact of the Muncy Till is generally with bed-rock, the lithology of the basal 0.3 to 0.6 m (1 to 2 ft) of till being strongly influenced by the underlying rock type. The top of the deposits is usually the ground surface; the upper 0.6 m (2 ft) is usually frost heaved and has a

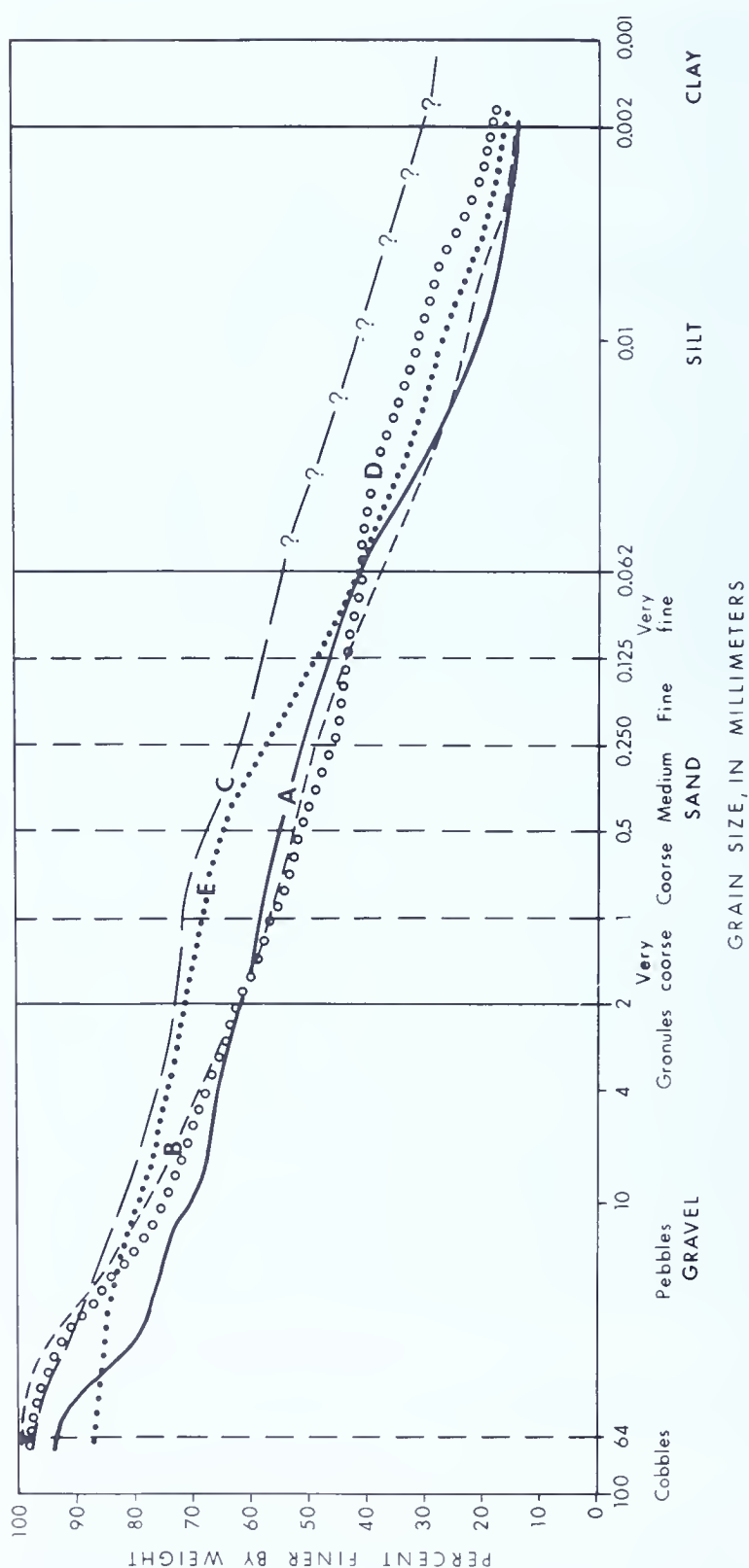


Figure 10. Grain size distribution curves of Muncy and Glen Brook Tills (A—D = Muncy Till; E = Glen Brook Till).

- A. Temporary excavation for a house foundation at the intersection of Briar Creek Township Routes 511 and 529, 1.2 km (0.7 mi) northeast of Evansville (41°04'55"N/76°17'09"W).
- B. Ditch on the east side of South Centre Township Route 646, 0.4 km (0.25 mi) north of Willow Springs (41°02'32"N/76°19'05"W).
- C. Excavation of the west side of Pa. Route 487 at Light Street (41°02'13"N/76°25'20"W).

- D. Excavation behind the gas station (out-of-business) on the north side of U. S. Route 11, 1 km (0.6 mi) northwest of Rupert (40°58'53"N/76°29'14"W).
- E. Bank on the west side of Legislative Route 19040 at the PennDOT storage area, 1.2 km (0.7 mi) northwest of Summer Hill (41°06'01"N/76°15'55"W).

loose texture. Muncy Till is overlain by alluvium in some stream valleys and by colluvium on many hillsides.

LANDFORMS: In valleys Muncy Till underlies smooth topography having low local relief. On the uplands, it forms discontinuous, eroded patches that have no distinctive topographic expression. Constructional landforms are not preserved.

AREAL DISTRIBUTION: Muncy Till is widely distributed in Greenwood Valley, the West Branch of Briar Creek valley, on the low upland crossed by Interstate Route 80 between the Light Street and Lime Ridge exits, and on the upland south of the Susquehanna River. It occurs as isolated patches in many other areas southwest of the Olean glacial border.

EXPOSURES: Poorly exposed within the mapped area, except in numerous temporary excavations. The only good exposure that is likely to remain accessible for some time is on the east side of the road to Michaels Meadow Campground, 1.6 km (1.0 mi) north of Almedia (41°01'45"N/76°23'26"W) (Figure 9).

ORIGIN: This till represents ground moraine deposited directly by continental ice sheets that advanced over the area from the northeast presumably in middle Pleistocene (Illinoian) time (between 375,000 and 150,000 years ago). The reddish-orange coloration of the till matrix and the decomposed or rubified nature of the clasts are a result of intense weathering during the Sangamonian Stage (interglacial).

Muncy Stratified Drift

GENERAL COMMENT: The term *Muncy stratified drift* is used informally to designate widespread deposits of sand and gravel whose areal distribution and weathering indicate that they are related to the ice advance that deposited the Muncy Till.

LITHOLOGY: This informal map unit comprises stratified deposits of sand, pebbles, cobbles, and occasional boulders to 0.3 m (1 ft) in diameter. Individual beds vary from well-sorted fine sand to moderately sorted sand and gravel. The thick deposit (30 m, or 100+ ft) at the Light Street interchange of Interstate Route 80, about 2.4 km (1.5 mi) northeast of Bloomsburg, appears to coarsen upward from fine sand containing red clay balls at the bottom to cobbly and coarse pebbly sand and gravel at the top. Cross-bedding and channeling are evident in most fresh exposures. Typical sand and gravel samples from Muncy stratified drift contain 5 percent silt and clay, 35 percent sand, and 60 percent gravel (Figure 11B-F), but some have a

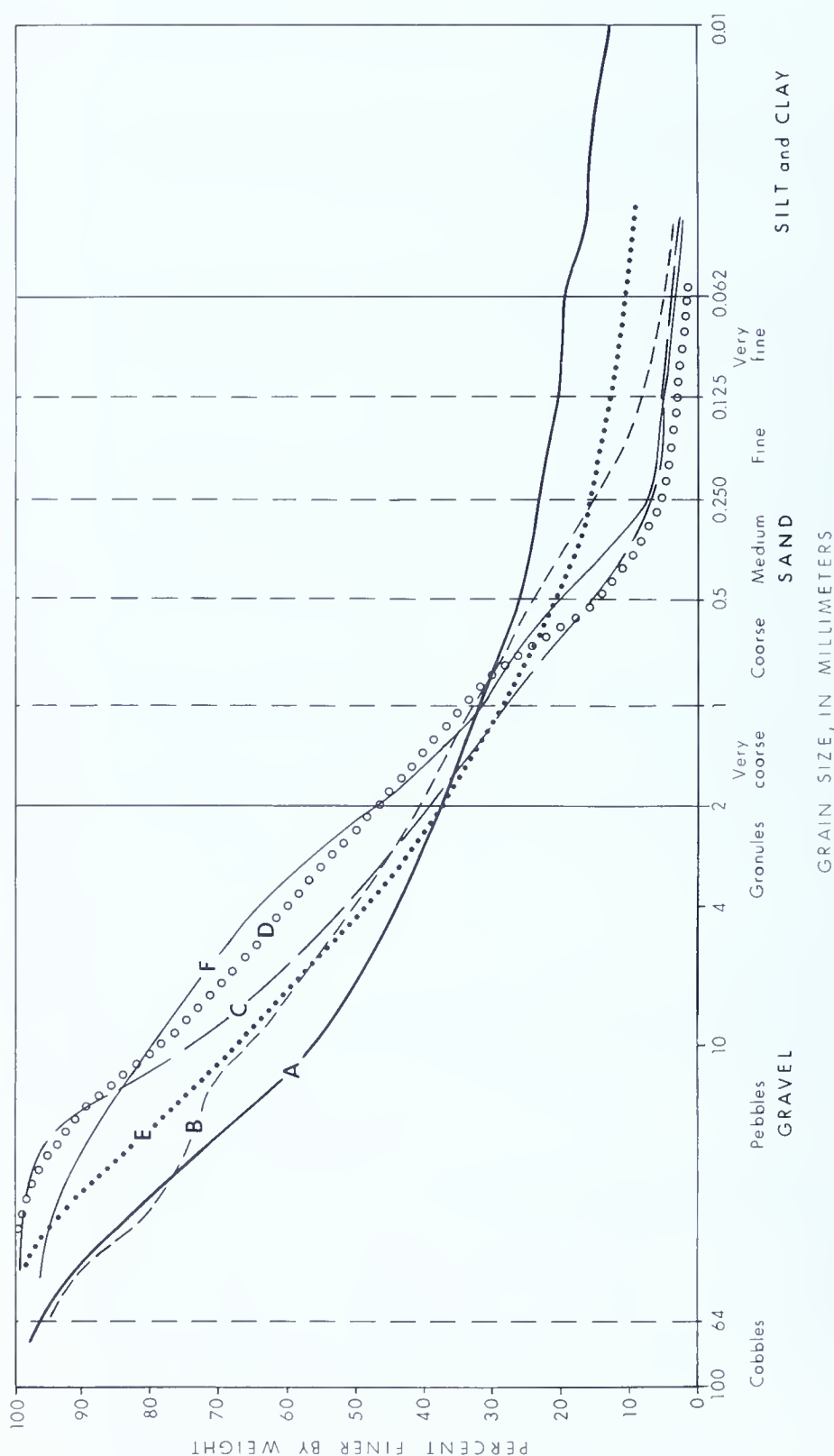


Figure 11. Grain size distribution curves of gravelly Muncy stratified-drift samples from the Bloomsburg and Catawissa quadrangles.

- A. East side of Legislative Route 19067 behind a farm equipment dealership, 1.1 km (0.7 mi) south of Bloomsburg (41°07'24"N/76°25'22"W).
- B. Temporary excavation (house foundation) on a hillside about 0.4 km (0.25 mi) southeast of Light Street (41°01'52"N/76°25'06"W).
- C and D. Gully on the north side of Interstate Route 80 at the west end of the interchange about 1 km (0.6 mi) south.

- E. Gully on the south side of Interstate Route 80 at the west end of the interchange about 1 km (0.6 mi) southwest of Light Street (41°01'38"N/76°25'53"W).
- F. Abandoned gravel pit on a hilltop north of the Fishing Creek-Hemlock Creek confluence, about 1 km (0.6 mi) southwest of Fernville (40°59'50"N/76°28'27"W).

much greater percentage of fines (Figure 11A). Pebble-sized and larger clasts are mostly well rounded. The dominant pebble lithologies are light-olive-gray to medium-gray and grayish-red siltstone and very fine to fine-grained sandstone in the Fishing Creek valley and dark-gray claystone and light-olive-gray to medium-gray, very fine to fine-grained sandstone in the Susquehanna Valley (Figure 12). Clast lithology is somewhat more diverse in drift that is situated along the Susquehanna, but all deposits are composed mostly of lithologies that are common within the present drainage basin of the North Branch of the Susquehanna River.

Deposits of Muncy stratified drift are deeply leached and oxidized; the weathering profile extends to a depth of 20 m (66 ft) in the deep cut at the Light Street interchange of Interstate Route 80. The weathered material is yellowish to reddish orange; the unweathered material is yellowish brown. Clasts in the weathered zone are usually soft and commonly rubified. Manganese oxide bands are conspicuous locally, and some deposits are firmly cemented by limonite.

THICKNESS: Ranges from a few meters to at least 28 m (90 ft).

CONTACTS: The lower contact is generally with bedrock, but logs of some borings in the vicinity of Light Street and Buckhorn suggest that Muncy Till may underlie stratified drift locally. Nescopeck Loess unconformably overlies Muncy stratified drift in some areas (e.g., at the Light Street interchange).

LANDFORMS: Typically forms broad, flat to gently rounded, terrace-like features at elevations of 200 to 210 m (660 to 690 ft).

AREAL DISTRIBUTION: The largest deposits of Muncy stratified drift occur in a 1.6-km- (1.0-mi-) wide belt between Buckhorn and Light Street. Scattered deposits outside this area are all of limited extent.

EXPOSURES: Generally poorly exposed; deep artificial cuts are slumped and covered by crown vetch. The best exposures are in gullies along Interstate Route 80 at the west end of the Light Street interchange. Other instructive exposures are located (1) near an abandoned asphalt plant on the north side of U. S. Route 11, 1 km (0.6 mi) northwest of Almedia (41°01'00"N/76°23'51"W); and (2) on the west side of Legislative Route 19026, 0.4 km (0.25 mi) north-northwest of Camp Creasy (41°01'56"N/76°27'07"W). Gravel at the latter locality has a limonite cement.

ORIGIN: Muncy stratified drift in the report area probably represents several types of Illinoian glaciofluvial deposition. The extremely thick deposits at Light Street appear to be remnants of a large kame or kame moraine. Other deposits of Muncy stratified drift within the mapped area appear to

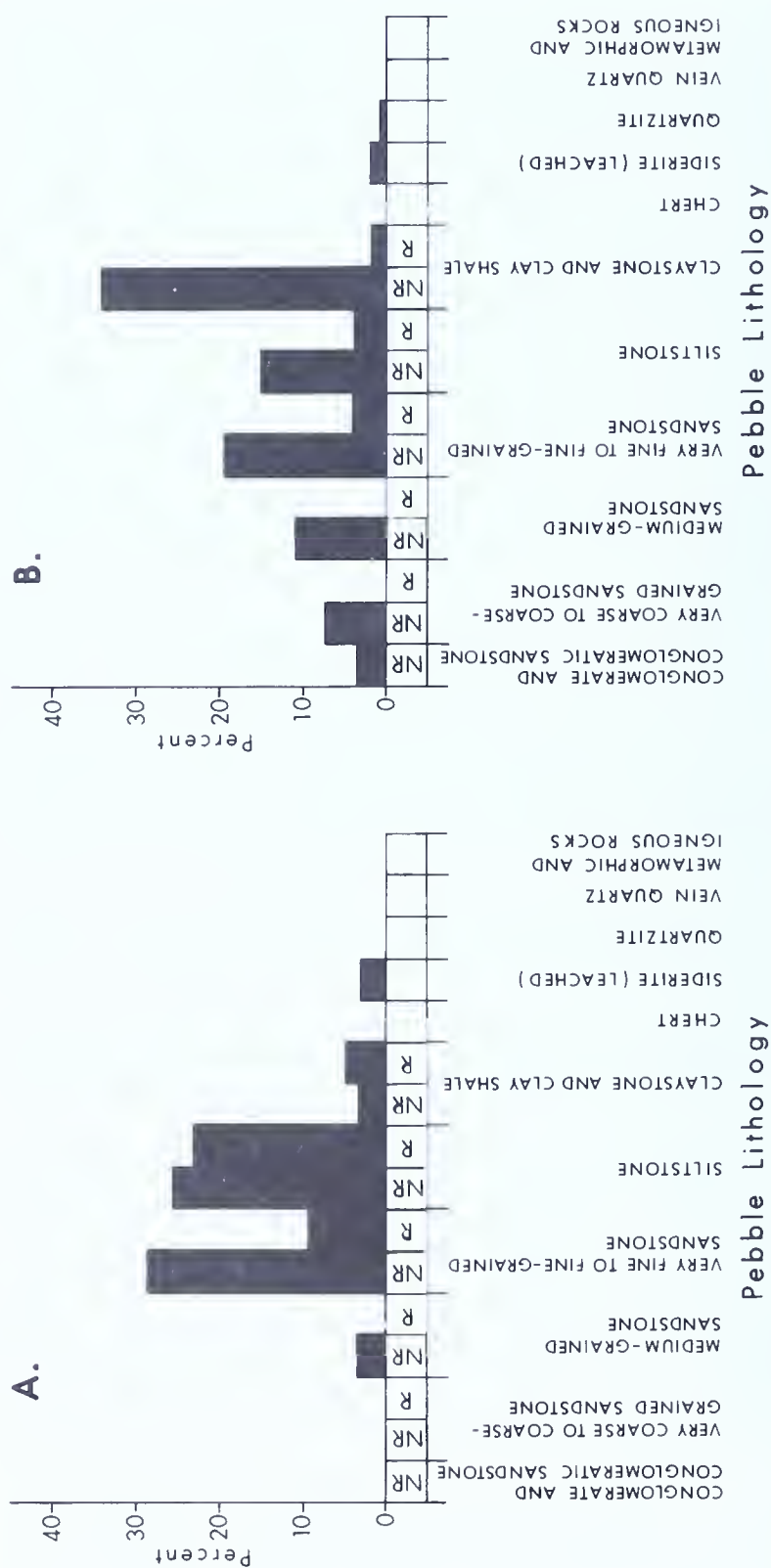


Figure 12. Histograms showing the lithologic composition of two deposits of Muncy stratified drift in the Bloomsburg and Mifflinville quadrangles, based on identification of 100 pebbles in the 1.0- to 3.0-cm (0.4- to 1.2-in.) size fraction (NR = nonred; R = red).

A. Gully on the north side of Interstate Route 80 at the west end of the interchange about 1 km (0.6 mi) south-west of Light Street (41°01'40"N/76°25'51"W).

B. Abandoned pit on the northeast side of Interstate Route 80, 1.4 km (0.9 mi) south of Mifflinville (41°01'08"N/76°18'21"W).

be remnants of outwash terraces or small pockets of ice-contact sand and gravel.

Pre-Nescopeck Loess

GENERAL COMMENT: The informal designation *pre-Nescopeck loess* is applied to a small deposit of probable wind-blown silt that apparently records an earlier period of eolian activity than the much less deeply weathered and more widespread Nescopeck Loess (see p. 58-61).

LITHOLOGY: Nonstratified, poorly sorted, bright-reddish-orange clayey silt that has a soft, sticky consistency. A typical sample is composed of about 10 percent fine and very fine sand, 55 percent silt, and 35 percent clay.

THICKNESS: 2 to 3 m (7 to 10 ft).

CONTACTS: Pre-Nescopeck loess overlies bedrock (Bloomsburg Formation) at the only known exposure, but probably succeeds Muncy Till or stratified drift in nearby covered areas. A few pebbles, probably derived from colluviation of Muncy Till on nearby slopes, occur in the upper 0.3 m (1 ft).

LANDFORMS: The loess caps a flat bedrock bench on the flank of a low hill, but does not itself have distinctive topographic expression.

AREAL DISTRIBUTION AND EXPOSURE: Occurs only in a small area about 1.8 km (1.1 mi) north-northwest of Lime Ridge. A small earthflow exposes about 2 m (7 ft) of deeply weathered loess at the top of a deep road-cut on Legislative Route 19101 (41°02'22"N/76°21'22"W) (see "Environmental Geology" section).

ORIGIN: The loess was deposited by periglacial wind action (Marchand and others, 1978), presumably following Illinoian glaciation. The original texture and color of the loess have been greatly modified by intense Sangamonian weathering.

Glen Brook Till

GENERAL COMMENT: The Glen Brook Till is named for exposures in a shallow gully just east of a small earth dam on a tributary of Glen Brook, 2.2 km (1.4 mi) north of Foundryville, Columbia County (41°05'56"N/76°14'17"W, Berwick quadrangle). See Appendix 1 for the type-section description. Although the Glen Brook Till is probably correlative with the Warrensville Till (Wells and Bucek, 1980) of Lycoming

County, the latter name is not adopted in this report because of the large unmapped area separating the type localities of the two units.

LITHOLOGY: Nonstratified, unsorted, cohesive mixture of clay, silt, sand, pebbles, cobbles, and frequent boulders, a few of which range up to 1.5 m (5 ft) in diameter. The Glen Brook is typified by a reddish-brown coloration and a sandy matrix. Textural analysis of a single sample showed a composition of 15 percent clay, 25 percent silt, 30 percent sand, and 30 percent pebbles and cobbles (Figure 10E). Large clasts are mostly subangular to subrounded. Although many boulders in the Glen Brook are white conglomerate and sandstone derived from the Pocono and/or Pottsville Formations, the great majority of the pebbles and cobbles are of Catskill Formation lithologies, e.g., light-olive-gray sandstone, grayish-red sandstone and siltstone, and purplish-gray banded sandstone. The reddish-brown color of the till also reflects the incorporation of much material from the Catskill.

The Glen Brook Till is clearly less deeply weathered than the Muncy Till. Except for a few deeply weathered clasts that may be reworked from older Muncy drift, most clasts are fresh or only moderately weathered. Weathering rinds vary from nonexistent to about 7 mm (0.28 in.) in thickness. Relatively unweathered pebbles of fine-grained lithologies are frequently striated. Where the recent soil profile is preserved, the upper 1 to 1.5 m (3 to 5 ft) of Glen Brook Till is altered to a yellowish-brown color.

THICKNESS: Averages 3 to 5 m (10 to 16 ft), but ranges up to 26 m (85 ft).

CONTACTS: The basal contact is presumably with bedrock throughout the mapped area. Along the south flanks of Knob and Lee Mountains, Glen Brook Till is overlapped by stony colluvium.

LANDFORMS: Depositional landforms are not preserved in areas of Glen Brook Till; the deposits mantle bedrock to shallow depths on hillsides and plug a few old valleys to depths that locally exceed 20 m (66 ft). Deposition of the till has apparently considerably subdued local relief in some areas.

AREAL DISTRIBUTION: The till forms a narrow, irregular belt varying from 0.3 to 1.8 km (0.2 to 1.1 mi) in width south of Knob and Lee Mountains between Orangeville and the eastern limit of the mapped area. The Glen Brook continues eastward to Salem Creek in the Berwick quadrangle.

EXPOSURES: The Glen Brook Till is poorly exposed, even in artificial excavations. Probably the best exposures within the mapped area are (1) on the west side of Legislative Route 19040 near a PennDOT storage area, 1.2 km (0.7 mi) northwest of Summer Hill (41°06'01"N/76°15'55"W); and (2) in excavations on the south side of Pa. Route 487, 1.2 km (0.7 mi) southwest of Orangeville (41°04'16"N/76°25'37"W).

ORIGIN: The Glen Brook Till was apparently deposited as ground moraine by a narrow lobe of an extensive early Wisconsinan (Altonian) continental glacier that covered northeastern Pennsylvania about 40,000 years ago. Another lobe of this glacier presumably deposited the Warrensville Till of Lycoming County.

Glen Brook Ice-Contact Stratified Drift

LITHOLOGY: This informal mapping unit comprises a crudely stratified and poorly sorted mixture of clay, silt, sand, pebbles, cobbles, and boulders; overall, the deposits exhibit the reddish-brown coloration and moderate weathering characteristic of the Glen Brook Till. Individual beds vary from poorly sorted, silty gravel that contains abundant rounded cobbles and boulders to moderately well sorted, fine to medium sand. The sand layers are lenticular and 15 cm (0.5 ft) or less in thickness. In some poorly defined gravelly beds, the pebbles and cobbles occur randomly in a weakly cohesive silt-clay matrix; in other beds the clasts are nested together and have little interstitial material. Coarse clasts are mostly rounded to sub-rounded and unweathered to moderately weathered, except for frequent olive-gray, micaceous, fine-grained sandstone pebbles and cobbles that are soft and deeply weathered. Striations are common on fine-grained clasts.

THICKNESS: Approximately 18 m (60 feet).

CONTACTS: The basal contact is probably with bedrock (Trimmers Rock Formation). The upslope lateral margins may be overlapped by colluvium.

LANDFORMS: The unit underlies a narrow terrace that is plastered against a steeply sloping hillside.

AREAL DISTRIBUTION AND EXPOSURE: The only known occurrence of Glen Brook ice-contact stratified drift is on the east side of Fishing Creek, 1.2 km (0.7 mi) north of Light Street. At this location, a large, recurrent debris slide in an unstable cut along Pa. Route 487 (41°03'03"N/76°25'43"W) exposes a good section through the deposit (see "Environmental Geology" section).

ORIGIN: Probably deposited by meltwater streams and mudflows at or near the margin of the Glen Brook (Altonian) ice sheet.

Olean End Moraine

GENERAL COMMENT: Cowl and Sevon (1980) have applied the name Olean to all drift of presumed Woodfordian age in northeastern and north-central Pennsylvania. Olean drift in the mapped area probably dates from about 15,000 years ago.

LITHOLOGY: Complex, heterogeneous deposits consisting of mixed till and stratified drift. The till is a nonstratified, unsorted, compact mixture of clay, silt, sand, pebbles, cobbles, and occasional boulders to 1 m (3 ft) in diameter; the stratified drift is predominantly sand, pebbles, and cobbles. Most clasts are subrounded to well rounded, but the till contains appreciable angular debris that was derived locally. As a result of the inclusion of considerable material from the Mauch Chunk Formation, the dominant color of both till and stratified drift is reddish brown. Although the relative percentages of the two components is uncertain, water wells in Little Shick-shinny Creek valley east of the mapped area are known to penetrate considerable thicknesses of stratified sand and gravel (Inners, 1978).

THICKNESS: Varies from 15 to 25 m (50 to 80 ft) in the vicinity of the Camp Louise dam.

CONTACTS: Probably directly overlies bedrock and grades laterally into Olean ground moraine.

LANDFORMS: Weakly to moderately developed depositional topography. The ground surface is somewhat rolling and irregular.

AREAL DISTRIBUTION: Occurs only in the extreme northeast corner of the Mifflinville quadrangle, east and south of the Camp Louise dam.

EXPOSURES: No natural or artificial cuts in Olean end moraine are known within the mapped area.

ORIGIN: Deposited in part by meltwater and in part directly by glacial ice near the border of the Woodfordian continental glacier, probably at a time of relative stability in the position of the ice margin.

Olean Ground Moraine

LITHOLOGY: Till, a nonstratified, unsorted mixture of clay, silt, sand, pebbles, cobbles, and boulders that has a moderately cohesive, silty clay matrix. Boulders 0.3 to 0.6 m (1 to 2 ft) in diameter are common, and a few range up to 2.5 m (8 ft). Pebble-sized and larger clasts are angular to well rounded; clasts of fine-grained lithologies (olive-gray to grayish-red sandstones and siltstones) may be striated. The color of the deposit ranges from moderate brown in areas dominated by Pocono debris to reddish brown where Catskill and Mauch Chunk bedrock prevails.

THICKNESS: Average is probably 2 to 3 m (7 to 10 ft); maximum is about 15 m (50 ft).

CONTACTS: The basal contact is with bedrock. Ground moraine is overlapped by boulder colluvium in Little Shickshinny Creek valley and by boulder colluvium and stony colluvium on the north side of Huntington Mountain. In Huntington Creek valley, Olean ground moraine is partially gradational into Olean kame moraine.

LANDFORMS: Vague depositional topography is observed in areas of Olean ground moraine. Deposits generally conform closely to the underlying bedrock topography, but tend to smooth out irregularities. Aside from a few projecting boulders, the ground-moraine surface is relatively smooth.

AREAL DISTRIBUTION: Occurs only in the northeastern part of the Mifflinville quadrangle, where it underlies the floor of Little Shickshinny Creek valley from Camp Louise westward nearly to Legislative Route 19040, the lower scarp slope of Huntington Mountain, and the eastern portion of the upland north of Huntington Creek.

EXPOSURES: Exposures of this deposit are rare. A few shallow artificial cuts reveal about 1 to 2 m (3 to 7 ft) of till. The best exposure is on the west side of Legislative Route 19108, 3.0 km (1.9 mi) northeast of Forks (41°07'15"N/76°19'51"W).

ORIGIN: Olean ground moraine was deposited directly beneath active glacial ice or by the ablation of debris-laden ice during retreat of the Woodfordian glacier.

Olean Ice-Contact Stratified Drift

LITHOLOGY: Crudely to well-stratified, moderately to poorly sorted deposits of sand, pebbles, cobbles, and frequent boulders 0.3 to 0.6 m (1 to 2 ft) in diameter. Coarse clasts are angular to well rounded, are mostly hard and unweathered, and consist predominantly of medium-gray to light-olive-gray and grayish-red sandstone and siltstone derived from the Catskill and Trimmers Rock Formations (see "Mineral Resources" section).

THICKNESS: 3 to 10 m (10 to 33 ft).

CONTACTS: The basal contact is uncertain, but may be with Olean kame moraine or ground moraine. Olean ice-contact stratified drift probably grades laterally into adjacent deposits.

LANDFORMS AND AREAL DISTRIBUTION: Forms a narrow, elongate esker and a tri-lobed kame alluvial fan in Huntington Creek valley and

an indistinct mound in Little Shickshinny Creek valley. The top of the kame alluvial fan is indented by a 5-m- (16-ft-) deep kettle.

EXPOSURE: The only vertical cut in Olean ice-contact stratified drift is in an abandoned borrow pit on the north side of Huntington Creek, about 1 km (0.6 mi) southwest of Jonestown (41°07'28"N/76°18'46"W).

ORIGIN: The esker-kame alluvial fan complex was deposited by glacial meltwater in an open ice channel (esker) and on an alluvial fan at or near the Woodfordian ice front. Melting of an ice block that was buried in the alluvial-fan sediments formed the kettle. The mound deposit in Little Shickshinny Creek valley may represent meltwater deposition in a small crevasse.

Olean Kame Moraine

LITHOLOGY: Stratified deposit of sand, pebbles, cobbles, and numerous boulders ranging to 0.6 m (2 ft) in diameter. It is characterized by abrupt lateral and vertical variations in grain size and sorting, ranging from poorly sorted, coarse cobbly gravel to moderately well sorted, fine to medium sand. Pebble-sized and larger clasts are subangular to well rounded and mostly unweathered.

THICKNESS: Up to 26 m (85 ft).

CONTACTS: Kame moraine probably overlies bedrock over most of its extent. Lateral contacts are with Olean ground moraine to the north and south and Olean outwash to the southwest.

LANDFORMS: Underlies hummocky terrain bounded by moderately steep valley sides. Local relief on the surface of the deposit is 6 m (20 ft) or less, and there are many closed or partially closed depressions.

AREAL DISTRIBUTION: Occurs in Huntington Creek valley between Jonestown (in the Stillwater quadrangle) and the Josiah Hess covered bridge east of Forks.

EXPOSURE: The only significant vertical exposure is in a small borrow pit on the Glenn Lamoreau farm about 1.5 km (0.9 mi) southwest of Jonestown (41°07'15"N/76°19'06"W).

ORIGIN: Deposited by glacial meltwater during the terminal ice stillstand and early deglaciation phases of the Woodfordian. Much of the deposit accumulated over, or directly adjacent to, stagnant glacial ice. Subsequent melting of buried or entrained ice blocks created the hummocky topography that characterizes the kame moraine.

Olean Outwash

LITHOLOGY: Stratified, moderately to well-sorted deposits of sand, pebbles, cobbles, and some boulders to 0.45 m (1.5 ft) in diameter (Figure 13). Outwash generally consists of irregularly alternating, lenticular beds of pebbly sand and gravel and fine to coarse sand, but at least one thick deposit (located 1.2 km, or 0.7 mi, southwest of Light Street) is almost exclusively very fine to medium sand. Pebble-sized and larger clasts are typically unweathered and generally well rounded. Most clasts are of local derivation, but considerable exotic material (chert, metamorphic and igneous pebbles, etc.), as well as abundant particulate anthracite coal, occurs in outwash along the Susquehanna River. Crossbedding and channeling are common (Figure 14). Gravel beds generally exhibit imbrication of flat or discoidal pebbles, and the sands are often profusely rippled. Elongate depressions that mark channelways on the outwash terraces may contain pockets



Figure 13. Typical exposure of Olean outwash, showing a wide range in grain size and excellent rounding of pebbles and cobbles, in an abandoned borrow pit on the south side of Pa. Route 339, about 3 km (2 mi) east of Mifflinville (41°02'10"N/76°15'51"W). The shovel is 0.7 m (27 in.) long.



Figure 14. Pebbly sand and gravel overlying crossbedded, medium to coarse sand, in Olean outwash in a high terrace remnant on the north side of U. S. Route 11 about 200 m (660 ft) west-southwest of the Tennytown Motel and 0.6 km (0.4 mi) north-east of Espy ($41^{\circ}00'46''\text{N}/76^{\circ}24'34''\text{W}$). Crossbedding (accentuated by coaly streaks) was formed by currents that flowed toward the southwest (left side of photograph).

of soft sandy clay or organic muck. (See “Mineral Resources” section for detailed textural and lithologic analyses of Olean outwash.)

THICKNESS: Variable, ranging from 6 m (20 ft) or less to at least 21 m (70 ft).

CONTACTS: The basal contact is usually with bedrock, but the outwash may locally overlie the Muncy or Glen Brook Tills. A thin veneer of Nescopeck Loess caps the deposit in some areas.

LANDFORMS: Forms intermediate and high terrace groups at 10 to 12 m (33 to 39 ft) and 18 m (59 ft), respectively, above low water on the Susquehanna River and equivalent terraces at about 12 m (39 ft) above low water on Fishing and Huntington Creeks. The main terrace levels are relatively flat and featureless except for: (1) incised, poorly drained channelways, 3 to 6 m (10 to 20 ft) deep, that mark old meltwater courses; and (2) erosional scarps (risers), 3 to 10 m (10 to 33 ft) high, that define the individual terrace elements. Particularly impressive risers separate the main terrace groups.

AREAL DISTRIBUTION: Occurs extensively along streams that served as meltwater discharge channels for the Woodfordian ice sheet, i.e., the Susquehanna River, Fishing Creek, and Huntington Creek.

EXPOSURES: Olean outwash is well exposed in many gravel pits, most of which are no longer active. Notably good exposures are located: (1) in pits 150 m (500 ft) east of Mifflin Township Route 640 near the cemetery in Mifflinville (41°01'47"N/76°18'15"W); (2) about 125 m (500 ft) north of Legislative Route 19025, 1.3 km (0.8 mi) west-northwest of Catawissa (40°57'17"N/76°28'43"W); (3) on the north side of Legislative Route 19031 near the U. S. Geological Survey gaging station, 1.1 km (0.7 mi) west of Orangeville (41°04'41"N/76°25'44"W); and (4) in the active sand pit (Plant No. 2) of the Bloomsburg Sand and Gravel Company, on the south side of Interstate Route 80, 1.2 km (0.7 mi) southwest of Light Street (41°01'32"N/76°26'10"W).

ORIGIN: Deposited by braided meltwater streams that issued from the Woodfordian ice sheet. Successive terrace levels formed by erosion and deposition as the streams were graded to new ratios of water volume to sediment load during glacial retreat.

Alluvium and Olean Outwash, Undifferentiated

LITHOLOGY: Stratified, moderately to well-sorted deposits of sand, pebbles, cobbles, and a few boulders to 0.3 m (1 ft) in diameter. Bedding variations are similar to those in Olean outwash, individual beds ranging from medium sand to pebbly sand and gravel. Channeling and crossbedding are conspicuous in fresh exposures. Pebble-sized and larger clasts are well rounded and unweathered to slightly weathered. Most coarse clasts are of local derivation; medium-gray to light-olive-gray sandstones and siltstones of Catskill and Trimmers Rock provenance constitute much of the gravel fraction, especially in Fishing Creek valley. Particulate anthracite coal is locally abundant in sands along the Susquehanna River. (See "Mineral Resources" section for detailed textural and lithologic analyses of alluvium and Olean outwash, undifferentiated.)

THICKNESS: Ranges from 1 to 15 m (3 to 50 ft), probably averaging about 7 m (23 ft).

CONTACTS: This surficial deposit usually overlies bedrock, but may locally succeed Glen Brook or Muncy Tills. The deeper portions of the deposits are laterally continuous with Olean outwash.

LANDFORMS: Underlies floodplains and low terraces along major streams. The deposits form relatively flat terrain into which modern streams are entrenched 1 to 5 m (3 to 15 ft). Low gravel bars within the existing channels of Fishing Creek and the Susquehanna River are included in this unit.

AREAL DISTRIBUTION: Occurs adjacent to streams that served as glacial meltwater channels in late Woodfordian time; i.e., the Susquehanna River, Fishing Creek, and Huntington Creek.

EXPOSURES: These deposits are poorly exposed. The upper 2 to 3 m (7 to 10 ft) is revealed by a diversion ditch on the south side of Fishing Creek valley, 2.0 km (1.2 mi) northeast of Orangeville (41°05'34"N/76°23'50"W). Several meters of material can also be seen at the top of the dredging pits of the Bloomsburg Sand and Gravel Company, 0.5 km (0.3 mi) west of Light Street (41°02'06"N/76°25'36"W). Partial exposures are also evident in an abandoned gravel pit on the west side of Interstate Route 80, about 1.2 km (0.7 mi) southwest of Mifflinville (41°01'26"N/76°19'30"W).

ORIGIN: Originally deposited as meltwater outwash during the late phase of Woodfordian deglaciation. The outwash sediments were subsequently entrenched by modern streams, reworked to a depth of several meters, and blanketed with recent alluvium. Deposition of alluvium takes place mainly during seasonal or catastrophic floods.

Nescopeck Loess

GENERAL COMMENT: The Nescopeck Loess is named for exposures in abandoned pits at the foot of the "River Hill" escarpment, about 0.4 km (0.2 mi) south of Nescopeck, Luzerne County (41°02'45"N/76°12'52"W, Berwick quadrangle). The description of the type section of Nescopeck Loess is given in Appendix 1. The distribution of loess shown on Plate 2 is based partly on soils maps by Parrish (1967).

LITHOLOGY: Nonstratified to poorly stratified, poorly sorted, compact, very fine sandy silt that has a distinctive dark-yellowish-orange color. An average sample of Nescopeck Loess is composed of approximately 9 percent clay, 58 percent silt, 16 percent very fine sand, 9 percent fine sand, 6 percent

medium sand, and 2 percent coarse sand (Figure 15). On bedrock slopes the loess often contains scattered angular, granule-sized shale chips. Typical exposures appear structureless and homogeneous, and vertical cuts have a tendency to fail by block-caving.

Nescopeck Loess develops a deep, generally well drained soil that commonly extends to depths of 1.3 to 1.8 m (4 to 6 ft) (Parrish, 1967). The soil zone is enriched in clay below a depth of approximately 0.3 m (1 ft). In areas of very thin cover, coarse clasts derived from underlying surficial deposits or bedrock are mixed with the loess mantle as a result of frost action or plowing. Areas of thick loess, however, have practically no coarse material at or near the surface.

THICKNESS: Variable, ranging from 0.3 m (1 ft) or less to 4 m (13 ft). The thinnest deposits occur on bedrock hilltops; the thickest are banked against slopes.

CONTACTS: Nescopeck Loess disconformably overlies many older surficial units as well as bedrock. Where the loess overlies bedrock, the upper meter (3 ft) or so of rock is generally deformed and intensely fractured by frost action (Figure 16). Loess may locally have interbedded or gradational contacts with shaly colluvium, suggesting that the two types of deposits formed contemporaneously (Inners, 1978).

LANDFORMS: Loess forms a discontinuous blanket over the land surface and tends to smooth out topographic irregularities.

AREAL DISTRIBUTION: Widely distributed over the southern part of the mapped area, particularly in the vicinity of the Susquehanna River. The intermediate and high Olean outwash terraces generally are covered to a depth of up to 1.5 m (5 ft). Loess also occurs over much of the glaciated (Muncy) shale upland northeast of Bloomsburg. Only scattered patches are known in the northern half of the area.

EXPOSURES: Nescopeck Loess is exposed only in artificial excavations. Several meters of loess overlying shale (Onondaga) bedrock is well exposed in a borrow pit on the north side of U. S. Route 11 at the Pa. Route 42 South interchange, 1.0 km (0.6 mi) northwest of Rupert ($40^{\circ}59'05''\text{N}/76^{\circ}28'59''\text{W}$).¹ Lesser thicknesses can be observed capping Olean outwash in many gravel pits throughout the area, e.g., behind the American Legion Post, 1.0 km (0.6 mi) northwest of Catawissa ($40^{\circ}57'21''\text{N}/76^{\circ}28'24''\text{W}$).

ORIGIN: Deposited by winds that blew across a sparsely vegetated, periglacial landscape in latest Woodfordian and/or early post-Woodfordian

¹ Loess from this locality was apparently once used as molding sand (Stone and American Foundrymen's Association, 1928).

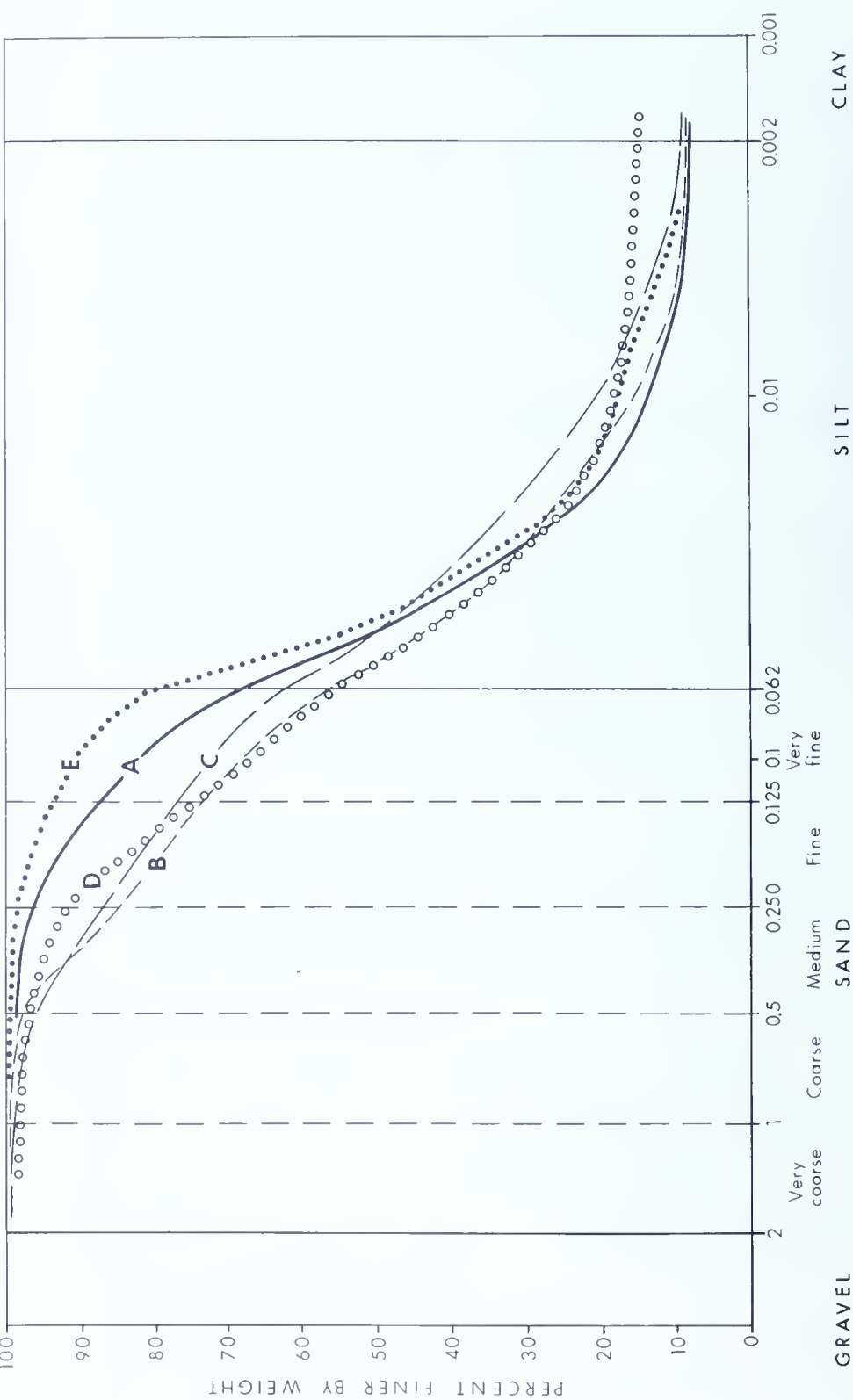


Figure 15. Grain size distribution curves of Nescopeck Loess.

- A. Abandoned pit about 0.4 km (0.25 mi) south of Nescopeck, Luzerne County (41°02'45"N/76°12'52"W, Berwick quadrangle).
 B. Sewer-line trench on East 5th Street, 2.25 km (1.4 mi) south of Nescopeck, Luzerne County (41°02'45"N/76°12'52"W, Berwick quadrangle).
 C. Temporary excavation on the north side of Legislative Route 19025, about 2.1 km (1.3 mi) west-northwest of Catawissa (40°57'20"N/74°00'22"W).
 D. Abandoned pit at the American Legion Post, 1 km (0.6 mi) northwest of Catawissa (40°57'21"N/76°28'24"W).
 E. Temporary excavation on the north side of Legislative Route 19025, about 2.1 km (1.3 mi) west-northwest of Catawissa (40°57'20"N/74°00'22"W).

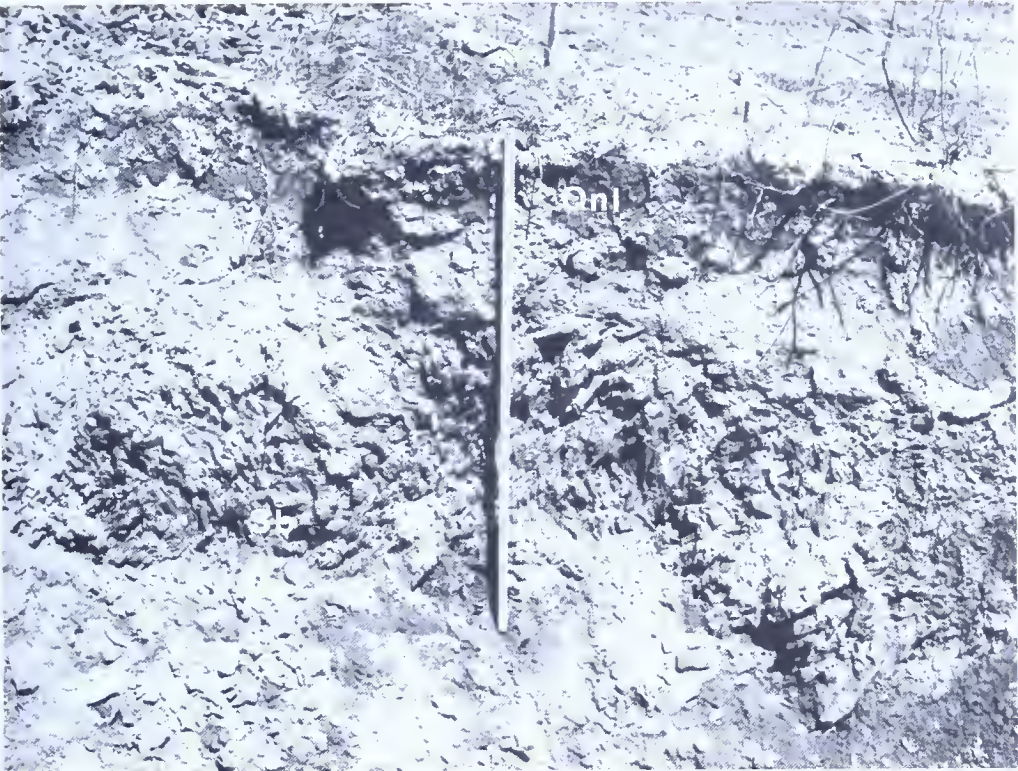


Figure 16. Nescopeck Loess (Qnl) overlying frost-riven and convoluted red shale of the Bloomsburg Formation (Sb) in a temporary excavation in the Shawnee Hills housing development, 2.6 km (1.6 mi) east-northeast of the Bloomsburg town square (41°00'47"N/76°25'47"W). The loess mantle here is about 45 cm (1.5 ft) thick, the upper 27 cm (0.9 ft) being topsoil. The staff is 1.5 m (5 ft) long.

time (Peltier, 1949). Most of the silt and fine sand that constitute the loess was winnowed from the Olean outwash deposits. The widespread occurrence of loess on the northwest side of the Susquehanna Valley strongly suggests that the predominant wind direction was from the east or southeast.

Talus

LITHOLOGY: Small, open-framework accumulations of sandstone and conglomerate boulders at the base of bedrock ledges. Boulders in talus are angular to subangular and range from 0.3 to 3 m (1 to 10 ft) in maximum diameter, averaging about 1 m (3 ft); most are blocky and slabby, their size and shape being determined by the spacing and orientation of bedding partings and joints in the bedrock. Individual boulders are randomly oriented and are occasionally unstable. Talus deposits shown on Plate 2 are derived from the Pocono Formation and the Duncannon Member of the Catskill Formation.

THICKNESS: Probably 2 m (7 ft) or less in most deposits.

CONTACTS: The basal contact is with bedrock at the upslope margin. The deposits grade laterally and downslope into boulder colluvium or stony colluvium.

LANDFORMS: Occurs on steep to moderately steep slopes at the maximum angle of repose. The surface of talus deposits is extremely irregular; many boulders protrude 0.3 to 0.6 m (1 to 2 ft) above the general terrain.

AREAL DISTRIBUTION: The only mapped deposits are near the crests of Knob and Lee Mountains. The largest accumulation occurs at the nose of Knob Mountain, 0.4 km (0.2 mi) east of Orangeville.

EXPOSURE: Vertical cuts through talus are unknown within the mapped area. The most accessible surface occurrence is on the east side of Legislative Route 19040 at the crest of Lee Mountain, 2.7 km (1.7 mi) northwest of Summer Hill (41°06'35"N/76°16'48"W).

ORIGIN: Talus is generated by the breakup of bedrock ledges along bedding planes, joints, and random fractures. Probably the most important processes contributing to talus formation are frost riving and root wedging. Although new material is presently being added at the head of some accumulations, most of the talus formed under the severe periglacial conditions that prevailed in the area during late Wisconsinan time.

Boulder Colluvium

LITHOLOGY: Unsorted to very poorly sorted mixture of fine and coarse materials that is characterized by an abundance of quartzitic sandstone and conglomerate boulders, usually angular to subangular blocks and slabs 0.3 to 1 m (1 to 3 ft) in diameter. The largest boulders are about 3 m (10 ft) across. The deposits lack internal stratification, but boulders tend to be concentrated on the surface as a result of frost heaving. A yellowish-gray, fine sandy matrix is typically present, but on steep slopes and in spring-fed gullies the matrix is often removed to a depth of about 1 m (3 ft). Most boulders are derived from the Pocono Formation, but some have a Duncannon Member provenance. Thick sandstones in other units, notably the Irish Valley Member of the Catskill Formation, also give rise to local concentrations of boulder colluvium.

THICKNESS: Probably averages 1 to 3 m (3 to 10 ft), but some deposits are at least 6 m (20 ft) thick.

CONTACTS: The base of these deposits is in contact with bedrock at the upper margin. Boulder colluvium overlaps Olean ground moraine on the

lower part of mountain slopes behind the Olean glacial border, and grades laterally and downslope into stony colluvium in other areas.

LANDFORMS: Mostly underlies rough, moderately steep to steep mountain slopes. Boulder colluvium also forms long gelifluction lobes up to 60 m (200 ft) wide that occupy transverse swales and narrow ravines in mountainous areas.

AREAL DISTRIBUTION: These deposits blanket the upper scarp slopes and lower dip slopes of Lee and Huntington Mountains and the scarp slopes of eastern Knob Mountain. Boulder colluvium also fills the upper end of the cove at the headwaters of Little Shickshinny Creek. Gelifluction lobes composed of boulder colluvium occur on north-facing slopes at the junction of Huntington and Knob Mountains. A small deposit of boulder colluvium derived from sandstone in the Irish Valley Member fills the bottom of a small ravine about 1.8 km (1.1 mi) northwest of Catawissa.

EXPOSURES: Boulder colluvium is rarely exposed in vertical cuts. A 1.8-m- (6-ft-) high exposure on the west side of Legislative Route 19040 at the crest of Lee Mountain (41°06'40"N/76°16'55"W) exhibits the diagnostic surface boulder concentration and fine sandy matrix. A typical surface expression of boulder colluvium can be seen on the dip slope of Huntington Mountain near the entrance to Camp Louise (41°07'10"N/76°16'55"W). The gelifluction lobes are splendidly developed on the mountain slopes south and southwest of the Harold Sones farmhouse, 2.5 km (1.5 mi) east of Forks (41°06'36"N/76°20'00"W).

ORIGIN: Boulder colluvium formed mainly under periglacial climatic conditions in late Wisconsinan time. Its origin was two phased. Phase one involved the initial formation of the boulders by intense frost riving of bed-rock ledges. Phase two was the gradual downslope movement of the boulders and the incorporation of sandy matrix derived from surface disintegration of the individual blocks. The gelifluction lobes record shallow, seasonal downslope flow of water-logged, bouldery debris, probably when permafrost existed at depth.

Stony Colluvium

LITHOLOGY: An unsorted to poorly sorted mixture of clay, silt, sand, and angular to subangular sandstone fragments. Large clasts are mostly 10 to 15 cm (0.3 to 0.5 ft) in diameter, ranging up to 1 m (3 ft), and are commonly concentrated near the ground surface. The grayish-red to orangish-brown silty fine sand to sandy clay matrix usually constitutes more than 50 percent of these deposits. Sandstone fragments are predominantly olive gray to grayish red (Duncannon Member of Catskill Formation) or dusky

red and ferruginous (Centre Member of Rose Hill Formation). No internal stratification is evident.

THICKNESS: Highly variable; deposits may be up to 10 m (33 ft) thick on lower hillslopes, but probably average about 3 m (10 ft).

CONTACTS: The basal contact is generally with bedrock, but stony colluvium overlaps Glen Brook Till on the south side of Knob and Lee Mountains. Deposits on Lee and Huntington Mountains and on the east end of Knob Mountain grade upslope into boulder colluvium.

LANDFORMS: Forms broad blankets and narrow tongues on steep to moderately steep mountain slopes. The surface of the deposits is moderately rough and stony due to the concentration of cobbles and boulders on the surface by frost heaving.

AREAL DISTRIBUTION: Occurs on the scarp slopes of Lee, Huntington, and Knob Mountains, and at the east end of Montour Ridge.

EXPOSURES: Stony colluvium is very poorly exposed. The best of a few artificial excavations in this material is situated on the north side of Pa. Route 93, about 0.8 km (0.5 mi) east of Orangeville, approximately at the eastern borough boundary (41°04'41"N/76°24'17"W).

ORIGIN: Stony colluvium was developed by downslope movement of debris, primarily under the periglacial conditions that prevailed throughout the area in late Wisconsinan time.

Shale-Chip Rubble

LITHOLOGY: Crudely to well-stratified deposits made up of poorly to moderately well sorted, chippy and platy, angular to subrounded clay shale and siltstone fragments 1 to 5 cm (0.4 to 2 in.) in diameter. Some deposits have an open-framework texture (Figure 17), whereas others have a sparse orangish-brown, silty clay matrix. Fragments are commonly aligned parallel to the upper surface of these deposits. Beds in well-stratified accumulations are lenticular and range from about 0.15 to 1 m (0.5 to 3 ft) thick.

The shale-chip rubble deposits on the west side of the gap at Fernville contain abundant angular sandstone blocks and slabs (to 0.3 m, or 1 ft, in diameter) derived from the Centre Member of the Rose Hill Formation.

THICKNESS: Variable, ranging from less than 1 m (3 ft) at upslope margins to at least 5 m (16 ft) near the bottom of slopes.

CONTACTS: The basal contact is with bedrock. Shale-chip rubble apparently grades laterally into colluvium.



Figure 17. Shale-chip rubble derived from the lower part of the Trimmers Rock Formation, in a cut along a private drive about 0.7 km (0.4 mi) north of Fowlersville ($41^{\circ}04'01''\text{N}/76^{\circ}19'41''\text{W}$). Note the abundant angular to subrounded siltstone fragments (some of which are rather equant), the lack of fine matrix, and the distinct decrease in grain size upward. The hammer is 28 cm (11 in.) long.

LANDFORMS: Underlies moderate to steep, smooth slopes.

AREAL DISTRIBUTION: Broad shale-chip rubble slopes occur south of Montour Run and on the west side of the gap at Fernville, northwest of Bloomsburg. The smaller deposits mapped near Fowlersville and on the south side of Greenwood valley may be representative of potentially more extensive shale-chip rubble deposits that can be differentiated from ordinary colluvium only by excavation.

EXPOSURES: Shale-chip rubble is well exposed in a few roadcuts and borrow pits. Good examples are located: (1) on the west side of Hemlock Township Route 360 in the gap at Fernville ($41^{\circ}00'37''\text{N}/76^{\circ}28'20''\text{W}$);

(2) along a private road at the south edge of the Summer Hill escarpment, 0.8 km (0.5 mi) north of Fowlersville (Figure 17); and (3) at the south edge of a large borrow pit in Greenwood Valley, 1.4 km (0.9 mi) north of Welliversville (41°06'38"N/76°28'26"W).

ORIGIN: These deposits were developed mainly in the late Wisconsinan by disintegration of shale and siltstone beds in the Rose Hill (lower member), Mahantango, Harrell, and Trimmers Rock Formations, followed by downslope movement and deposition through sheetflow, mudflow, and gelifluction (Sevon and Berg, 1979).

Colluvium

LITHOLOGY: Nonstratified to crudely stratified, unsorted, mostly angular to subangular rock fragments in a silty clay matrix. The composition and size range of the fragments are largely dependent on the lithology and fragmentation characteristics of the bedrock occurring upslope, but some deposits contain significant admixtures of colluvial Muncy or Glen Brook Till. Coarse clasts are commonly 3 to 10 cm (1 to 4 in.) in diameter, but range up to 0.6 m (2 ft). The overall color varies according to the color of the parent bedrock; it is mostly moderate yellowish brown to orangish brown in areas of nonred bedrock, and grayish red where red bedrock predominates. Colluvium is locally weathered reddish orange. Vague convolutions are evident in some well-exposed deposits. Areas mapped as colluvium may include unrecognized accumulations of shale-chip rubble.

THICKNESS: Highly variable, ranging from zero at the upslope margin to at least 5 m (16 ft) near the bottom of some slopes.

CONTACTS: The basal contact is generally with bedrock, although it may overlap Muncy or Glen Brook Till at the bottom of some slopes. Most deposits grade upslope into regolith and downslope into alluvium and colluvium, undifferentiated.

LANDFORMS: Occupies moderate to steep slopes on uplands having intermediate elevations and also valleys and headwater areas of many small streams.

AREAL DISTRIBUTION: Widely distributed in the mapped area. Colluvium is especially well developed at the base of Trimmers Rock escarpments south of Greenwood Valley, between Hemlock and Fishing Creeks, north of West Branch of Briar Creek valley (Summer Hill), and south of the Susquehanna River (River Hill).

EXPOSURES: Natural exposures of colluvium are relatively rare, but some streams have undercut and partially exposed thick colluvial deposits

on steep valley sides; e.g., Stony Brook about 1.6 km (1 mi) above its mouth. Artificial excavations in colluvium are relatively common. One of the best exposures is in an abandoned borrow pit on the east side of Legislative Route 19023, 1.6 km (1 mi) south of Mifflinville (41°01'03"N/76°18'07"W).

ORIGIN: Formed by downslope movement of disintegrated and weathered bedrock and locally admixed glacial till. Most colluvial deposits are probably relicts of Pleistocene periglacial mass movement, but deposits on steep to moderately steep slopes probably still experience slow creep. The thick colluvial deposit south of Mifflinville that is mentioned above records two distinct periods of colluviation. At this locality an older, orangish-red colluvium (Illinoian?) is abruptly overlain by yellowish-brown colluvium (late Woodfordian).

Holocene

Alluvial Fan

LITHOLOGY: Small, crudely stratified, moderately sorted deposits of silt, sand, pebbles, and cobbles. Subangular and subrounded gravel derived from the Trimmers Rock Formation and Muncy Till constitutes 25 to 50 percent of alluvial-fan deposits. The matrix is silty fine sand.

THICKNESS: Probably 3 m (10 ft) or less.

CONTACTS: Basal and lateral contacts are usually with undifferentiated alluvium and Olean outwash.

LANDFORMS: These deposits are broadly fan shaped in plan view. Individual alluvial fans have local relief of 2 to 3 m (7 to 10 ft).

AREAL DISTRIBUTION: Occur at mouths of short tributary streams on the south side of the Susquehanna River, west-southwest of Mifflinville.

EXPOSURES: The surfaces of the fans are well exposed at low water, but internal structures are not visible.

ORIGIN: Formed by flushing out of narrow ravines during periods of high streamflow. The sudden decrease in flow velocity as the streams enter the flat floodplain of the Susquehanna River results in deposition of coarse material at points of discharge.

Alluvium and Colluvium, Undifferentiated

LITHOLOGY: A rather poorly stratified and poorly sorted mixture of clay, silt, sand, pebbles, cobbles, and boulders. Subangular to subrounded,

pebble-sized and larger clasts make up 25 to 50 percent of the deposits. The shape and lithology of the large clasts is determined to a great extent by the nature of the bedrock on the slopes of individual stream valleys. Rounded clasts of erratic lithologies are common in glaciated areas, however. The matrix in these deposits is usually sandy silt or silty clay.

THICKNESS: Variable, generally 1 to 4 m (3 to 13 ft).

CONTACTS: Generally overlies bedrock, but may overlie Muncy or Glen Brook Till in some areas. The deposits grade laterally into colluvium on the slopes of most valleys.

LANDFORMS: Forms gently concave areas on the floors of intermittent stream valleys in which floodplains are not well developed.

AREAL DISTRIBUTION: Occurs locally throughout the report area, particularly along streams dissecting the broad upland between Greenwood Valley and Fishing Creek.

EXPOSURES: Poorly exposed. One meter (3 ft) or less is exposed in some places along incised streams.

ORIGIN: Formed mostly by downslope movement of surficial materials into valleys that have only weak and intermittent stream action.

Stony Alluvium

LITHOLOGY: Crudely stratified, poorly to moderately sorted mixture of silt, sand, pebbles, cobbles, and some boulders. Locally derived pebble-sized and larger clasts constitute about 50 percent of the deposits; they are mostly angular to subrounded, and are commonly platy and discoidal in areas of sandstone and siltstone bedrock. Pebbles and cobbles are generally conspicuously imbricated. Well-rounded clasts are common only where streams dissect glacial deposits. The matrix in these deposits is fine to coarse sand.

THICKNESS: Variable, probably 1 to 2 m (3 to 7 ft) in most valleys.

CONTACTS: The basal contact is generally with bedrock, but may be with Muncy or Glen Brook Till locally. Stony alluvium grades laterally and upstream into colluvium.

LANDFORMS: Forms flat floodplains on the floors of narrow valleys in hilly terrain. Some broader floodplains may exhibit a braided pattern, having one active channel at low water, but several, separated by longitudinal gravel bars, at high water.

AREAL DISTRIBUTION: Occurs along many upland streams that have medium gradients. The largest deposits are in Stony Brook valley, about 2.4 km (1.5 mi) north of Light Street.

EXPOSURES: Poorly exposed; streams are generally incised less than 1 m (3 ft) into floodplains. Excellent imbrication of surface gravel is present along a small stream on the east side of Little Fishing Creek, 0.9 km (0.6 mi) north of the Wanich covered bridge (41°02'51"N/76°29'09"W).

ORIGIN: Stony alluvium is deposited by streams that erode colluvium from adjacent valley sides and redistribute the material over relatively flat floodplains.

Alluvium

LITHOLOGY: Stratified, moderately to well-sorted accumulations of clay, silt, sand, pebbles, and some cobbles and boulders. Alluvium is highly variable, its nature depending on the gradient, discharge, and sediment source of the depositing streams. Coarse pebbly sand and gravel occurs along the larger streams, such as Green Creek, Little Fishing Creek, and Hemlock Creek. Alluvium along sluggish streams having low gradients, such as Mud Run and the West Branch of Briar Creek, is mostly stiff clayey silt that contains lenses of small to medium pebbles. Pebble-sized and larger clasts are mainly of local derivation and are mostly subrounded to well rounded and platy to discoidal. Red or light-olive-gray siltstone and sandstone pebbles are particularly abundant. The sands and gravels are commonly crossbedded and channelled. The overall color of the alluvial deposits is typically dark yellowish brown or olive gray.

THICKNESS: Variable, ranging from less than 2 m (7 ft) to more than 10 m (33 ft).

CONTACTS: The basal contact is generally with bedrock, but in Greenwood Valley, the valley of the West Branch of Briar Creek, and Tenmile Run valley, alluvium overlies Muncy Till.

LANDFORMS: Except for a large, high-level deposit in Greenwood Valley southwest of Rohrsburg, alluvium forms the flat, modern floodplains of moderately large streams that did not receive glacial meltwaters in late Pleistocene time. The depth of recent stream intrenchment into the floodplains is generally 0.6 to 1.0 m (2 to 3 ft).

AREAL DISTRIBUTION: Occurs along the major tributaries of Fishing Creek (Mud Run-Green Creek, Little Fishing Creek, and Hemlock Creek), the various branches and major tributaries of Briar Creek, and the lower portion of Tenmile Run.

EXPOSURES: Natural and man-made exposures are relatively rare. Shallow cuts in alluvium can be examined on the west bank of Little Fishing Creek, 1.8 km (1.1 mi) northeast of Buckhorn (41°01'34"N/76°28'51"W) and in the bed of Mud Run, 60 m (200 ft) downstream of the Legislative Route 19029 bridge, 2.4 km (1.5 mi) north of Welliversville (41°07'10"N/76°28'39"W).

ORIGIN: Mostly deposited by present-day streams, particularly during periods of high flow. The deposit in Greenwood Valley that lies above the floodplains of Green Creek and Mud Run probably represents fluvial deposition in late Wisconsinan time.

STRUCTURAL GEOLOGY

The Bloomsburg and Mifflinville quadrangles and the northwestern part of the Catawissa quadrangle lie entirely within the Valley and Ridge province of the Folded Appalachians. Major folds in the mapped area are, from south to north, the Berwick anticlinorium, Lackawanna synclinorium, and Milton anticlinorium. The relatively simple structural configuration exposed at the ground surface is probably the expression of considerably greater structural complexity at depth. Structural relief of both the Berwick and Milton anticlinoria is probably due to ramping of faults from deep-seated décollements in the Lower Cambrian and Upper Ordovician (Figure 18; Gwinn, 1964; Faill and MacLachlan, 1980). Although subsurface faulting is probably extensive, few large faults break through to the surface. Of these, the Light Street fault is believed to be directly related to movement on the Upper Ordovician décollement. In addition to the major folds and faults, other structural features that are characteristic of the report area include minor folds and kinks, small wedge faults, cleavage, and joints.

The rocks in the Bloomsburg-Mifflinville-Catawissa area were deformed during the Alleghanian orogeny, about 250 million years ago. All of the structures described below were presumably formed at that time.

FOLDS

The Berwick and Milton anticlinoria and Lackawanna synclinorium are all first-order structures; i.e., their wavelength, or distance between adjacent hinges, is greater than 10 km (6 mi). A few third-order (20 m to 1 km, or 66 ft to 0.6 mi) folds are superimposed on the flanks of these large structures, and fourth-order (20 cm to 20 m, or 8 in. to 66 ft) drag folds and kink folds are frequently developed in thin- to medium-bedded rock units. That the folds were formed mainly by a flexural-slip mechanism is shown by: (1) the common occurrence of slickenlines on bedding surfaces; (2) maintenance of roughly the same bedding thickness across fold hinges; and (3) the

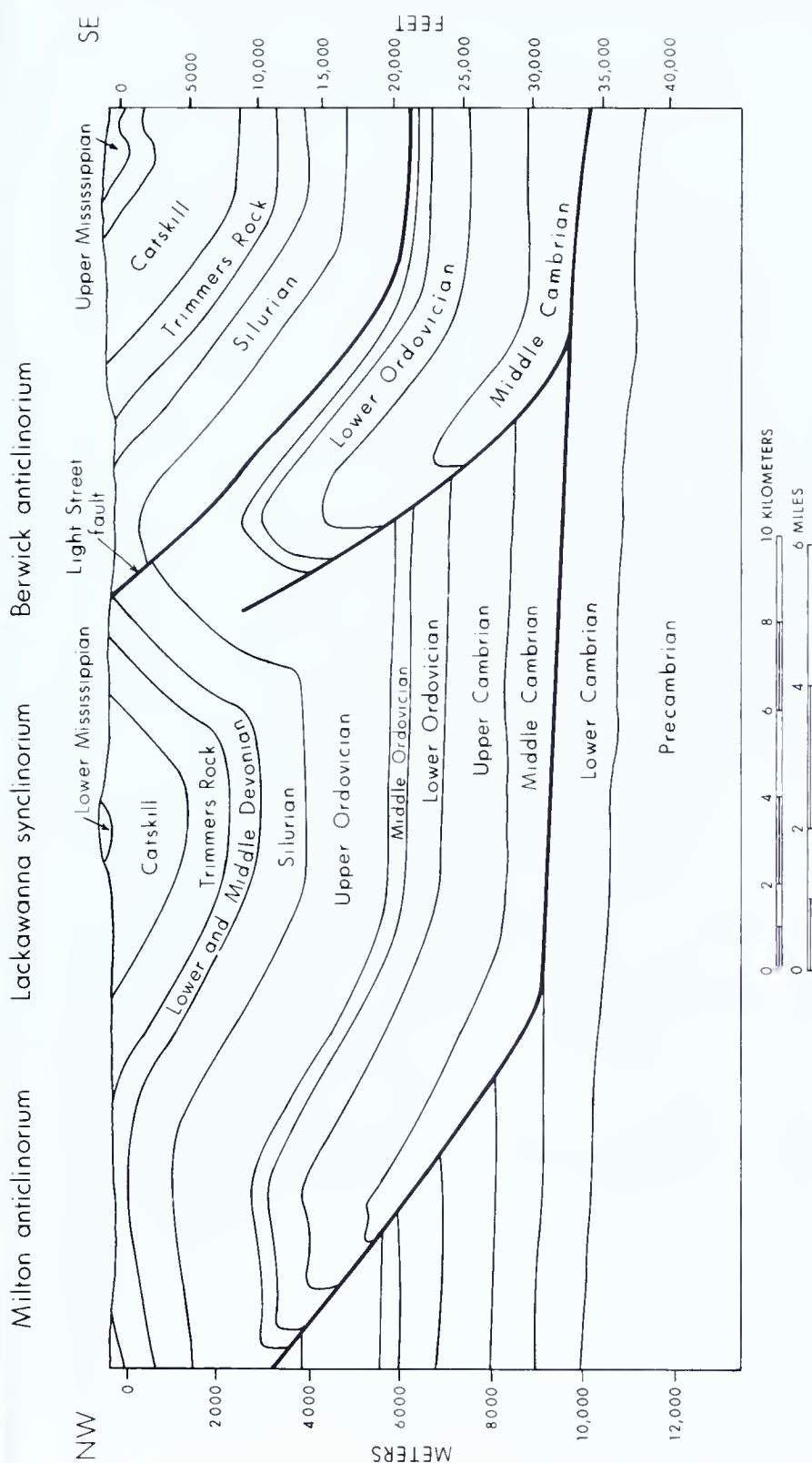


Figure 18. Generalized cross section of the Paleozoic rocks and Alleghanian structures in the Bloomsburg-Mifflinville and adjacent quadrangles. Note that the Berwick and Milton anticlinoria are interpreted to be localized over deep ramp thrusts that branch from a décollement, or sole fault, in the Lower-Middle Cambrian (after R. T. Faill, personal communication).

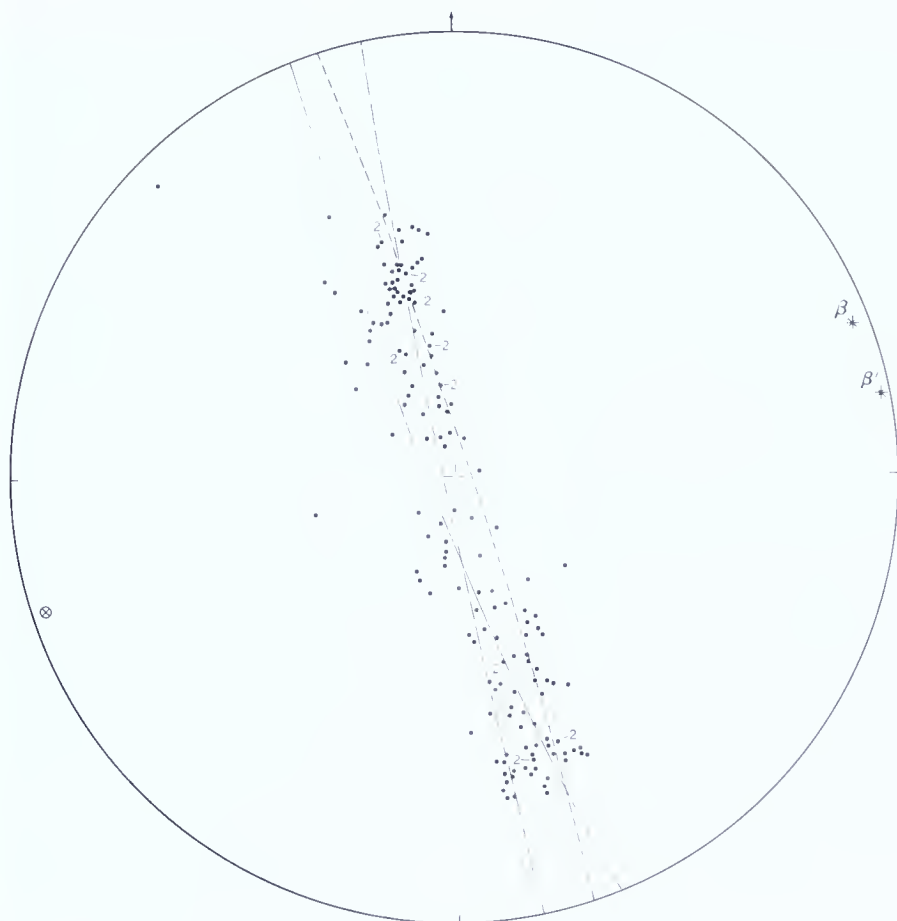
frequent occurrence of wedge faults (Donath and Parker, 1964). However, the prominent cleavage developed in argillaceous rocks of the Berwick anticlinorium suggests that flexural-flow folding may have been involved in the deformation of the southern part of the report area. Many of the major and minor folds exhibit the planar limbs and narrow fold hinges characteristic of kink-band folds (Faill, 1969, 1973).

Berwick Anticlinorium

The Berwick anticlinorium extends for approximately 110 km (70 mi) across northeastern Pennsylvania (Wood and Bergin, 1970) and is composed of at least five en echelon, doubly plunging segments. The plunge of the structure as a whole is to the east-northeast, each segment being offset slightly to the northeast.

Within the confines of the report area, the Berwick anticlinorium comprises the northeastern nose of the East Montour Ridge anticline and a 20.5-km (12.7-mi) portion of the Turkey Hill anticline. The en echelon offset between these two anticlines occurs at Hemlock Creek, about 2 km (1.2 mi) west of Bloomsburg. The dominant plunge of the anticlinorium is toward N70E at 4 degrees in the Bloomsburg quadrangle and N79E at 2 degrees in the Mifflinville quadrangle (Figure 19). West of the Bloomsburg-Scott Township line, the Turkey Hill anticline plunges about S70W at 1 to 5 degrees for a distance of about 4.8 km (3 mi); the fold terminates about 1 km (0.6 mi) west of Hemlock Creek. The wavelength of the anticlinorium in the vicinity of Bloomsburg is about 15.2 km (9.4 mi). Because of the somewhat steeper northeastward plunge of the Lackawanna synclinorium, apparent structural relief of the Berwick anticlinorium relative to the synclinorium increases from about 2,980 m (9,777 ft) at Bloomsburg to about 3,404 m (11,168 ft) at Berwick. Structural relief relative to the Northumberland (Catawissa-McCauley Mountain) synclinorium just south of the report area is somewhat greater. The anticlinorium is slightly asymmetrical, particularly in the central part of its trend (see cross sections B-B' and C-C' on Plate 1). Dips in excess of 50 degrees are common on the north limb, but rare on the south limb (Figure 19).

Although the Berwick anticlinorium is broadly cylindrical in cross section, the fold limbs are actually composed of planar segments separated by kink planes (abrupt changes in attitude). Portions of the fold hinge do have a uniform curvature, for example the great arch formed by the Centre Member of the Rose Hill Formation on the west wall of the gap at Fernville. The radius of curvature of the fold hinge at this point is approximately 1.25 km (0.78 mi) compared to a fold wavelength of 15.2 km (9.4 mi). Therefore, even such curved hinges are narrow as compared to the wavelength of the fold and appear to fit a kink geometry.



EXPLANATION

- | | | | |
|------------|---|---------|--|
| 2• | Pole to bedding. Number indicates two readings at same point. | — | π -circle, Bloomsburg quadrangle |
| β^* | Average fold axis, Bloomsburg quadrangle | - - - | π -circle, Mifflinville quadrangle |
| β'^* | Average fold axis, Mifflinville quadrangle | - - - - | π -circle, west end of Turkey Hill anticline |
| ⊗ | Fold axis, west end of Turkey Hill anticline | | |

Figure 19. Stereogram (equal-area lower hemisphere projection) of 172 poles to bedding in the Berwick anticlinorium (Rose Hill to Trimmers Rock Formations).

Lackawanna Synclinorium

The Lackawanna synclinorium occupies the central and northeastern portions of the report area. Regionally this great downwarp extends for a distance of approximately 190 km (120 mi) (Wood and Bergin, 1970), and in its deepest portion encloses the Northern Anthracite coal field of Luzerne and Lackawanna Counties.

In the Bloomsburg and Mifflinville quadrangles, the Lackawanna synclinorium is apparently a simple synclinal fold. Although the average plunge of the axis is about N74E at 4 degrees (Figure 20), the axial trace is decidedly nonlinear, and considerable variation in axial plunge exists. Vectors of plunge at selected localities along the axial trace are as follows:

South of Mordansville	N71E at 5 degrees
Nose of Knob Mountain	N77E at 7 degrees
Crest of Knob Mountain	N72E at 0 degrees
Junction of Lee and Huntington Mountains	N70E at 3 degrees

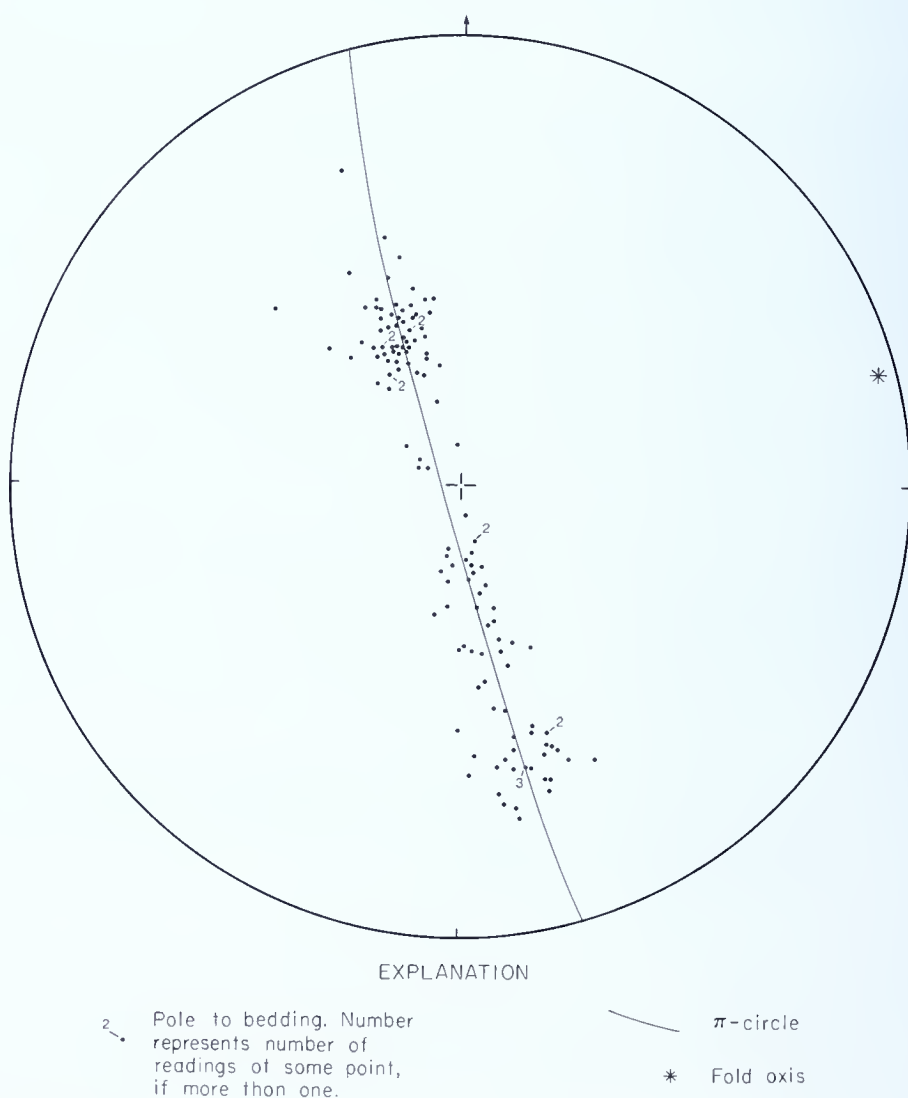


Figure 20. Stereogram (equal-area lower hemisphere projection) of 132 poles to bedding in the Lackawanna synclinorium (Catskill and Pocono Formations).

The approximately horizontal axis along the crest of Knob Mountain accounts for the long, narrow summit of that ridge. Similarly, an increase in plunge further to the northeast results in the bifurcation of Huntington and Lee Mountains from the east end of Knob Mountain. The wavelength of the Lackawanna synclinorium is approximately 12.1 km (7.5 mi), and its structural relief relative to the Milton anticlinorium is about 2,100 m (6,900 ft). The fold is distinctly asymmetrical; dips on the south limb (the north limb of the Berwick anticlinorium) commonly exceed 50 degrees, whereas those on the north limb are generally 40 degrees or less.

Milton Anticlinorium

The axis of the Milton anticlinorium, the northernmost first-order anticlinal fold east of the $76^{\circ}30'$ meridian in Pennsylvania, passes through Greenwood Valley in the extreme northwest corner of the Bloomsburg quadrangle. Although the overall plunge of the anticlinorial axis is toward the east-northeast, the axial plunge within the report area is uncertain. Apparently the axis plunges to the west-southwest in the eastern portion of the Millville quadrangle (J. H. Way, personal communication), but persistence of this plunge into the Bloomsburg quadrangle has not been substantiated. Because the northern limb of the Milton anticlinorium has limited exposure within the mapped area, an analysis of the structural configuration of the fold will not be attempted here.

Minor Folds and Kink Bands

Superimposed on the flanks of the major folds are a few poorly exposed or inferred third-order folds developed in Silurian and Lower to Middle Devonian rocks on the flanks of the Berwick anticlinorium. Fourth-order folds occur on the flanks of both the Berwick anticlinorium and the Lackawanna synclinorium. Some of these minor structures occur in the vicinity of thrust faults and may owe their origin to drag along the fault planes (Figure 21).

Except for the shallow syncline between the northeast-plunging East Montour Ridge and southwest-plunging Turkey Hill anticlines west of Bloomsburg, the only clearly demonstrated third-order folds in the report area are located on the south (upthrown) side of the Light Street thrust fault. The most conspicuous of these are several moderately to steeply plunging (to 27 degrees northeast) folds in the Keyser and Tonoloway Formations on the grounds of the Berwick Golf Club southeast of Martzville ($41^{\circ}03'57''\text{N}/76^{\circ}15'42''\text{W}$). East of the golf course, these folds apparently involve the Old Port-Onondaga interval as well. A third-order anticlinal-synclinal couple on the upthrown side of the Light Street fault is also defined by a ledge of southeast-dipping shaly limestone of the Old Port



Figure 21. Drag fold and fault (f) in laminated calcisiltite of the upper part of the Keyser Formation, beneath the U. S. Route 11 bridge over Fishing Creek, 2.2 km (1.4 mi) southwest of the Bloomsburg town square ($40^{\circ}59'22''\text{N}/76^{\circ}28'39''\text{W}$). The fold plunges N62E at 10 degrees. The hammer is 28 cm (11 in.) long.

Formation in the bed of the West Branch of Briar Creek, 0.7 km (0.4 mi) west of Center School ($41^{\circ}03'14''\text{N}/76^{\circ}21'28''\text{W}$).

On the south flank of the Berwick anticlinorium, a third-order fold in the Keyser-Old Port interval is inferred to exist south of U. S. Route 11 in the vicinity of the abandoned Lime Ridge quarry. Although bedrock in this area is covered by about 9 m (30 ft) of Olean outwash gravel, the presence of either a fault or minor fold is suggested by the fact that an industrial well drilled at the Poloran, Inc., plant encountered about 82 m (270 ft) of cavernous limestone (probably Keyser) about 100 m (330 ft) south of the expected outcrop trace of the top of the thick Upper Silurian-Lower Devonian limestone sequence.

Fourth-order folds are best developed in units that have numerous bedding anisotropies, such as interbedded shales and limestones or sandstones (Wills Creek, Tonoloway-Keyser, Trimmers Rock, and Catskill). Most of those folds are composed of two or more distinct kink bands; they generally exhibit sharp, narrow hinges and a downdip sense of rotation. Single kink bands that are 1 to 3 m (3 to 10 ft) wide are evident at many outcrops (Figure 22). Where only one kink plane is visible in large outcrops, it is pre-

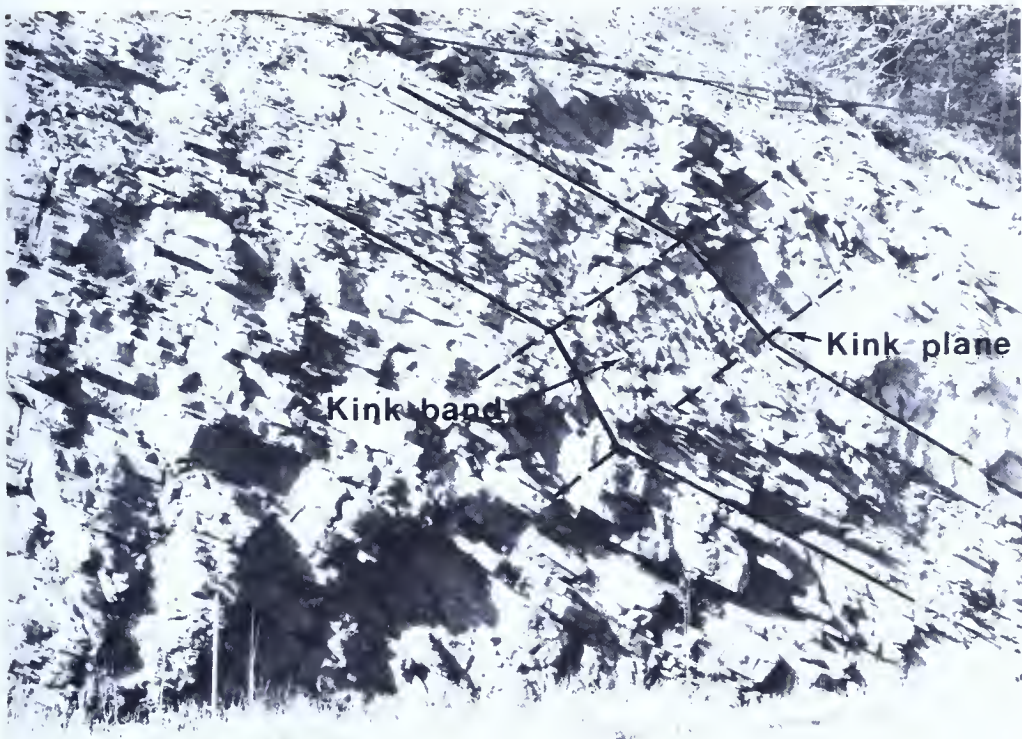


Figure 22. Kink band in red shale and sandstone of the Sherman Creek Member of the Catskill Formation, on the north side of Legislative Route 19068 at Twin Bridges Park, 0.5 km (0.3 mi) southeast of Forks ($41^{\circ}06'26''\text{N}/76^{\circ}21'25''\text{W}$). The staff on the left is 1.5 m (5 ft) long.

sumed that the rocks on either side of the kink plane are part of broad kink bands that define planar segments of the major fold limbs. Since minor fold and kink axes tend to approximate the trend and plunge of the average fold axis of the larger structures (Figure 23), both the large and small structures probably formed under similar kinematic conditions.

FAULTS

Outcropping faults in the report area occur on a variety of scales, ranging from one major thrust fault of regional significance to many small ruptures of only local extent and minimal displacement. The large faults are all poorly exposed or completely concealed beneath terrace gravels, and their existence is mainly inferred from missing stratigraphic section or apparent stratigraphic offsets. Small faults (mostly wedge and oblique faults) are observable in outcrop by offsets in bedding and the occurrence of slickensides on fracture surfaces.

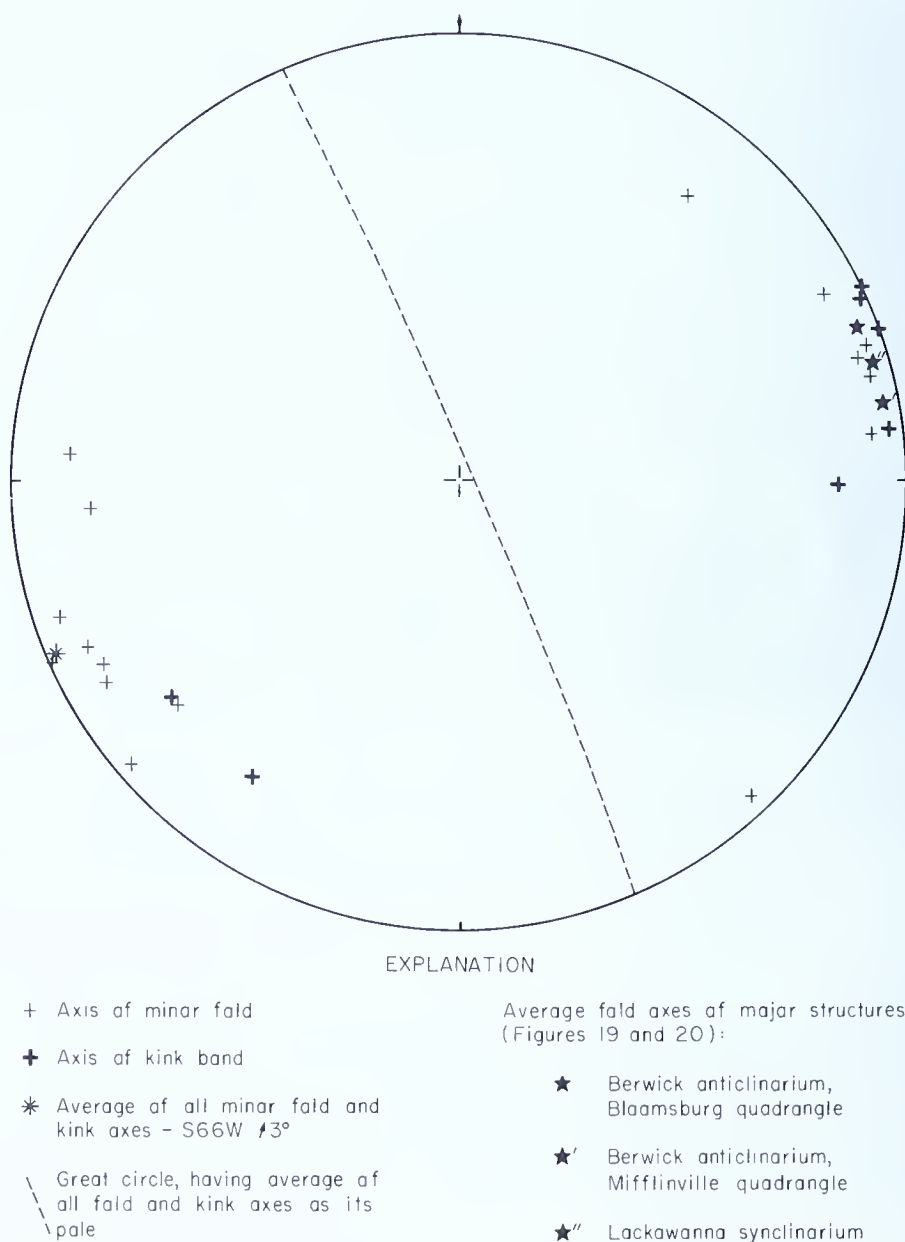


Figure 23. Stereogram (equal-area lower hemisphere projection) of 23 minor folds and kink bands.

Light Street Thrust Fault

The Light Street thrust fault is a poorly exposed zone of stratigraphic and structural disharmony that has been traced along the north side of the Berwick anticlinorium from the village of Mooresburg in Montour County eastward to Berwick, a distance of 43 km (27 mi) (Inners, 1978; Inners and Way, 1979; Way, in preparation). The western surface limit of the fault has

been fairly well defined by field mapping, but the eastern end is completely masked by Olean terrace gravel at Berwick.

Detailed mapping on the north limb of the Berwick anticlinorium in the Bloomsburg and Mifflinville quadrangles and areas to the west has revealed numerous localities where stratigraphic section is missing and geologic relationships can best be explained by postulating a major fault. A few such localities in the report area are: (1) very thin Mahantango Formation in Little Fishing Creek valley, about 1.7 km (1.1 mi) northeast of Buckhorn; (2) lower Tonoloway limestone in contact with upper(?) Marcellus black shale in Fishing Creek valley, 2.5 km (1.6 mi) west of Light Street ($41^{\circ}01'55''\text{N}/76^{\circ}27'07''\text{N}$); and (3) upper Tonoloway limestone in close proximity to Marcellus shale along an old railroad grade on the southwest side of the West Branch of Briar Creek, 1.0 km (0.6 mi) east of Dennis Mills ($41^{\circ}03'38''\text{N}/76^{\circ}18'27''\text{W}$).

Direct evidence of faulting has also been observed at several localities. In the bed of Frozen Run, about 1.5 km (0.9 mi) southwest of Buckhorn ($41^{\circ}00'34''\text{N}/76^{\circ}30'48''\text{W}$, Millville quadrangle), Wills Creek dolomite and shale overlies sheared and brecciated Mahantango shale (Williams, 1980). Sheared Marcellus shale is present at locality (2) above. Extensive faulting and brecciation probably related to the Light Street fault occurs in the Keyser and Old Port Formations in an abandoned quarry south of Pa. Route 42 about 1.6 km (1.0 mi) northeast of Buckhorn ($41^{\circ}01'31''\text{N}/76^{\circ}28'57''\text{W}$) and near the right abutment of Briar Creek dam, 1.4 km (0.9 mi) west of Martzville ($41^{\circ}03'52''\text{N}/76^{\circ}16'54''\text{W}$) (Dumper, unpublished report).

Indirect structural evidence for the Light Street fault is provided by numerous folds and bedding discordancies in the presumed fault zone. In addition to the possible third-order drag folds discussed earlier (p. 75), deformation along the fault is also shown by anomalous bedding attitudes in the Old Port Formation along the small creek east of Millertown Road (Legislative Route 19029) ($41^{\circ}01'46''\text{N}/76^{\circ}27'57''\text{W}$) and in the Marcellus Formation on the old railroad grade east of Dennis Mills. Highly contorted Tonoloway limestone on the northwest side of Fishing Creek valley west of Light Street (Figure 24) is also probably caused by drag along the fault.

Because the surface of the Light Street fault is nowhere well enough exposed to directly measure its attitude, any conclusions as to its geometry must be based on large-scale mapping considerations. The fault trace generally trends $\text{N}70\text{--}80\text{E}$, parallel to the structural grain of the region. The chief exception occurs at the western border of the Bloomsburg quadrangle approximately midway along the total length of the fault, where the trace changes to a $\text{N}50\text{--}55\text{E}$ direction for a distance of 2.5 km (1.6 mi). This change in fault trend corresponds with a jump in stratigraphic position from a Wills Creek/Marcellus level to a Marcellus/Mahantango level and



Figure 24. Intensely contorted, shaly, laminated limestone of the Tonoloway Formation, on the west side of Legislative Route 19026 0.5 km (0.3 mi) northwest of Camp Creasy ($41^{\circ}01'54''\text{N}/76^{\circ}27'06''\text{W}$). The deformation is believed to be related to the proximity of the Light Street thrust fault. The hammer is 28 cm (11 in.) long.

lies directly northwest of the en echelon offset between the East Montour Ridge and Turkey Hill anticlines. A southeast dip for the fault is indicated by missing stratigraphic section and thinning of units. Its highly irregular map trace, particularly in its western half (Millville, Danville, and Riverside quadrangles), suggests either a low-angle or nonplanar fault. The many drag folds on the upper plate also point to a relatively low angle fault, probably about 25 degrees, at least in the vicinity of its outcrop edge. However, if the Light Street thrust does arise from an Upper Ordovician décollement as shown in Figure 18, it must steepen to at least 50 degrees down dip and to the east (see cross sections on Plate 1). Stratigraphic displacement and net slip vary considerably along the outcrop trace of the fault. Both reach a maximum in Frosty Valley (Millville quadrangle) about 1.5 km (0.9 mi) southwest of Buckhorn (Way, in preparation). Within the report area, net slip appears to decline to the east as the fault plane steepens.

Although few clearly south dipping faults were observed along the trace of the Light Street fault, north-dipping faults are fairly common on the footwall side. Such faults transect warped Mahantango shale along Pa.

Route 93, 0.3 km (0.2 mi) north of Dennis Mills ($41^{\circ}03'50''\text{N}/76^{\circ}18'54''\text{W}$) and moderately north dipping Tully limy shale on the west side of Pa. Route 42, 2 km (1.2 mi) northeast of Buckhorn ($41^{\circ}01'46''\text{N}/76^{\circ}28'52''\text{W}$). The north-dipping faults are typically accompanied by gouge zones 10 to 30 cm (0.3 to 1 ft) wide (Figure 25) and may bear an antithetic relationship to the Light Street fault.

The Light Street thrust fault is here interpreted to be a ramp fault from a décollement beneath the Berwick anticlinorium (Figure 18). The fault probably arises from a secondary detachment in the Upper Ordovician (Reedsville-Antes interval) rather than from the main Valley and Ridge sole fault in the Lower Cambrian. Ramping and thrusting in the Upper Ordovician shales are presumably shown in the Reno Solomon No. 1 well drilled on the crest of Shamokin Mountain (Berwick anticlinorium), about 45 km



Figure 25. Fault and gouge zone in contorted Mahantango shale, on the north side of Pa. Route 93, 0.3 km (0.2 mi) north of Dennis Mills ($41^{\circ}03'50''\text{N}/76^{\circ}18'54''\text{W}$). The fault dips approximately 40 degrees to the north. The hammer is 28 cm (11 in.) long.

(28 mi) west-southwest of Bloomsburg. Since ramping on the Light Street fault can account for little of the structural relief exhibited by the Berwick anticlinorium within the report area, at least one other décollement and ramp thrust would have to exist at depth.

Espy and Berwick Faults

The Espy and Berwick faults are ruptures of significant length and displacement that are inferred to exist on the south flank of the Berwick anticlinorium between Bloomsburg and Berwick. Both are apparently large wedge faults that pass laterally into bedding-plane faults.

Evidence for the Espy fault includes: (1) repetition of the Tonoloway Formation (and presumably other units) in several abandoned quarries northeast of Espy; (2) occurrence of Old Port chert north of and structurally beneath Tonoloway limestone and dolomite near the abandoned Columbia Asphalt Company works on the north side of U. S. Route 11 (41°01'00"N/76°23'54"W); and (3) faulting and warping of the Old Port and Keyser in an abandoned quarry, about 450 m (1480 ft) west-northwest of the old asphalt plant (41°01'00"N/76°24'12"W). The Espy fault apparently cuts through the hinge of a third-order syncline whose geometry is obscured by the faulting and by a thick blanket of outwash gravel. The length of the fault is problematical, but it probably extends for at least 2 km (1.2 mi).

The Berwick fault has been discussed at some length by Inners (1978). Although this fault is shown on Plate 1 as extending into the east-central part of the mapped area, its position and displacement are entirely conjectural.

Minor Faults

In addition to the several large faults described above, the rocks of the Bloomsburg-Mifflinville area are cut by numerous minor faults which are confined to single outcrops and have very small displacements. Two distinct types are common—namely, wedge and oblique faults.

Wedge faults lie at small angles (10 to 30 degrees) to bedding and result in lateral shortening and duplication of beds (Cloos, 1961). Except for the large Espy and Berwick faults, wedge faults in the mapped area transect only one or several beds and have 1 m (3 ft) or less displacement (Figure 26). Minor wedge faults represent a simple transfer of displacement from one bedding surface to another. Slickenlines on wedge faults are congruent with those on bedding surfaces (Figure 27), indicating that the formation of the wedge faults is kinematically related to the bedding-slip movements that were probably a major mode of stress relief during folding (Faill and Wells, 1974).



Figure 26. Wedge fault transecting a sandstone bed in the Irish Valley Member of the Catskill Formation, on the west side of Legislative Route 19029, 2.1 km (1.3 mi) south of Millertown ($41^{\circ}02'42''\text{N}/76^{\circ}28'01''\text{W}$). The fault results in partial duplication and lateral shortening of the bed. Slickenlines (S) on the fault plane are perpendicular to the fold axis.

Oblique faults transect bedding strike at angles of approximately 30 to 45 degrees. Slickenlines on these faults are not congruent with slickenlines on bedding.

CLEAVAGE

Cleavage (i.e., closely spaced parallel partings or subparallel discontinuities that result from structural deformation) is a prominent feature affecting mainly argillaceous rocks of the Berwick anticlinorium. North of the axis of the Lackawanna synclinorium, cleavage was noted only as a minor foliation



Figure 27. Stereogram (equal-area lower hemisphere projection) of 15 poles to wedge faults, 14 slickenlines on wedge faults, and 51 slickenlines on bedding.

developed in clay shales or claystones that are in immediate contact with competent sandstone beds. Two types of cleavage have been differentiated on Plate 1: (1) a fine spaced cleavage developed in clay shales, silty clay shales, and claystones, mainly in the Marcellus and Mahantango Formations; and (2) a coarse spaced cleavage commonly present in the Rose Hill, Bloomsburg, Trimmers Rock, and Catskill Formations, and the Tully Member of the Mahantango Formation (Inners, 1978).

Fine cleavage is usually expressed by smooth partings that are generally less than 0.6 cm (0.24 in.) apart and impart a “shaly” appearance to the rock. Often this cleavage is the dominant outcrop foliation and almost completely obscures bedding, particularly in the Mahantango Formation on the north side of the Berwick anticlinorium (Figure 28).

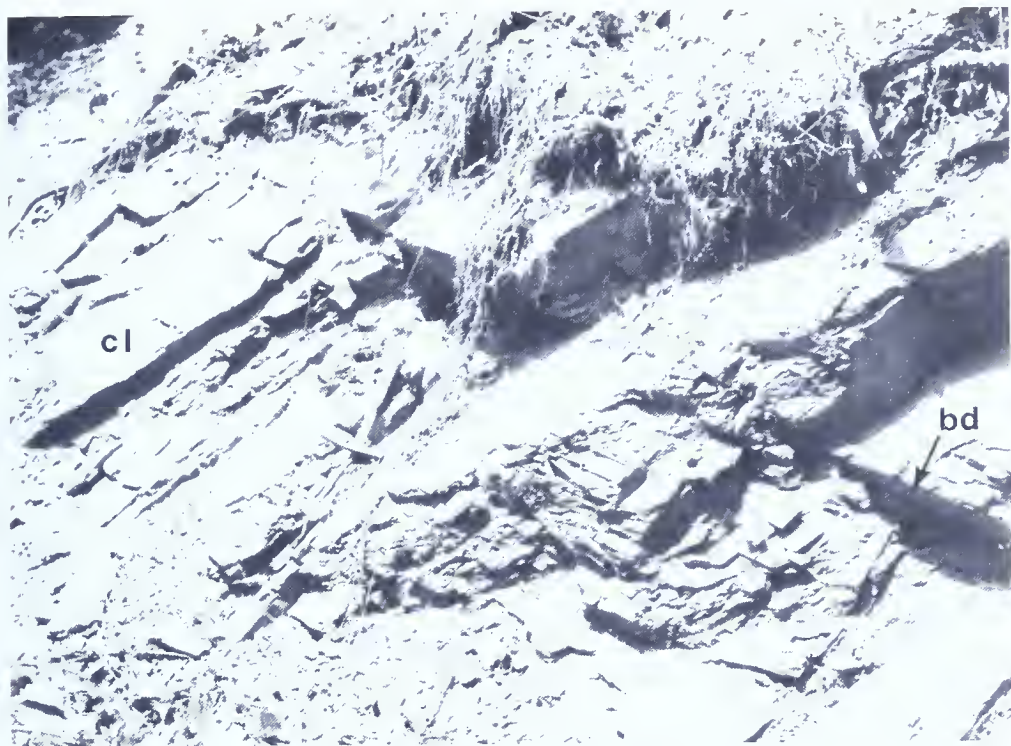


Figure 28. Intensely cleaved, gray silty clay shale of the lower member of the Mahantango Formation, in an abandoned borrow pit on the north side of Legislative Route 19042 near Briar Creek Lake, about 1.0 km (0.6 mi) west of Martzville ($41^{\circ}04'10''\text{N}/76^{\circ}16'46''\text{W}$). Fine cleavage (cl) dips 40 degrees to the southeast, and bedding (bd) dips 48 degrees to the northwest. The hammer is 28 cm (11 in.) long.

Coarse cleavage separations range from 1 cm (0.4 in.) to about 7.5 cm (3 in.). Cleaved surfaces are usually uneven and form the boundaries of elongate, uncleaved lenses of rock.

As in the Berwick quadrangle to the east (Inners, 1978), both fine and coarse cleavage generally dip to the south and fan slightly across the anticlinorium (Figure 29). On the north limb, cleavage dip averages about 45 degrees and ranges from 35 to 60 degrees; on the south limb, it averages about 70 degrees and ranges from 40 to 90 degrees. On the south side of the anticlinorium, coarse cleavage locally dips to the northwest at 40 to 50 degrees. The pole to the great circle defined by all cleavage measurements in the report area plunges N78E at 12 degrees (Figure 29).

Intersections of bedding and fine cleavage are straight, whereas those of bedding and coarse cleavage form wavy lineations. Both plunge gently to the northeast or southwest (Figure 29). The two clusters formed by the intersections—N68E at 5 degrees and N80E at 5 degrees—correspond rather closely to the average fold-axis plunges of the Berwick anticlinorium in the Bloomsburg and Mifflinville quadrangles, respectively.



Figure 29. Stereogram (equal-area lower hemisphere projection) of 43 poles to cleavage and 43 bedding-cleavage intersections.

JOINTS

Joints (i.e., planar fractures in the rock along which little or no movement has taken place) are developed in all lithologies, particularly in well-bedded sandstones and siltstones and fissile clay shales. Three types are recognized: (1) strike joints, i.e., those that strike essentially parallel to bedding strike; (2) dip joints, i.e., those that strike perpendicular to bedding

strike; and (3) oblique joints, i.e., those that strike obliquely to bedding strike. Although most joints are straight and smooth, some—particularly strike joints—are irregular and rough. They range from continuous fractures that transect a large stratigraphic thickness (Figure 30) to discontinuous breaks that are confined to one rock type and do not extend across lithologic boundaries.



Figure 30. Prominent strike joints in fissile, dark-gray clay shale of the lower member of the Mahantango Formation, on the north side of Legislative Route 19026, 0.6 km (0.4 mi) west of Light Street ($41^{\circ}02'24''\text{N}/76^{\circ}25'54''\text{W}$). Joints are mostly 15 to 30 cm (0.5 to 1 ft) apart and dip 62 degrees southeast. Bedding dips 36 degrees northwest (into the cut).

The orientations and statistical groupings of joints in the report area are shown in Figures 31, 32, and 33. Most strike and dip joints are oriented approximately normal to bedding planes and are roughly orthogonal. Strike joints fan across the major folds: in south-dipping beds they dip moderately to steeply north, whereas in north-dipping beds they are inclined to the south (see also Wood and others, 1969). Dip joints are approximately vertical regardless of structural position. (Note that the poles to dip joints tend to cluster around the average fold axes of the major folds.) Oblique joints are often inclined at moderate angles to bedding. Three or more sets (i.e., groupings of parallel joints) generally can be recognized on each limb of the major anticlinoria.

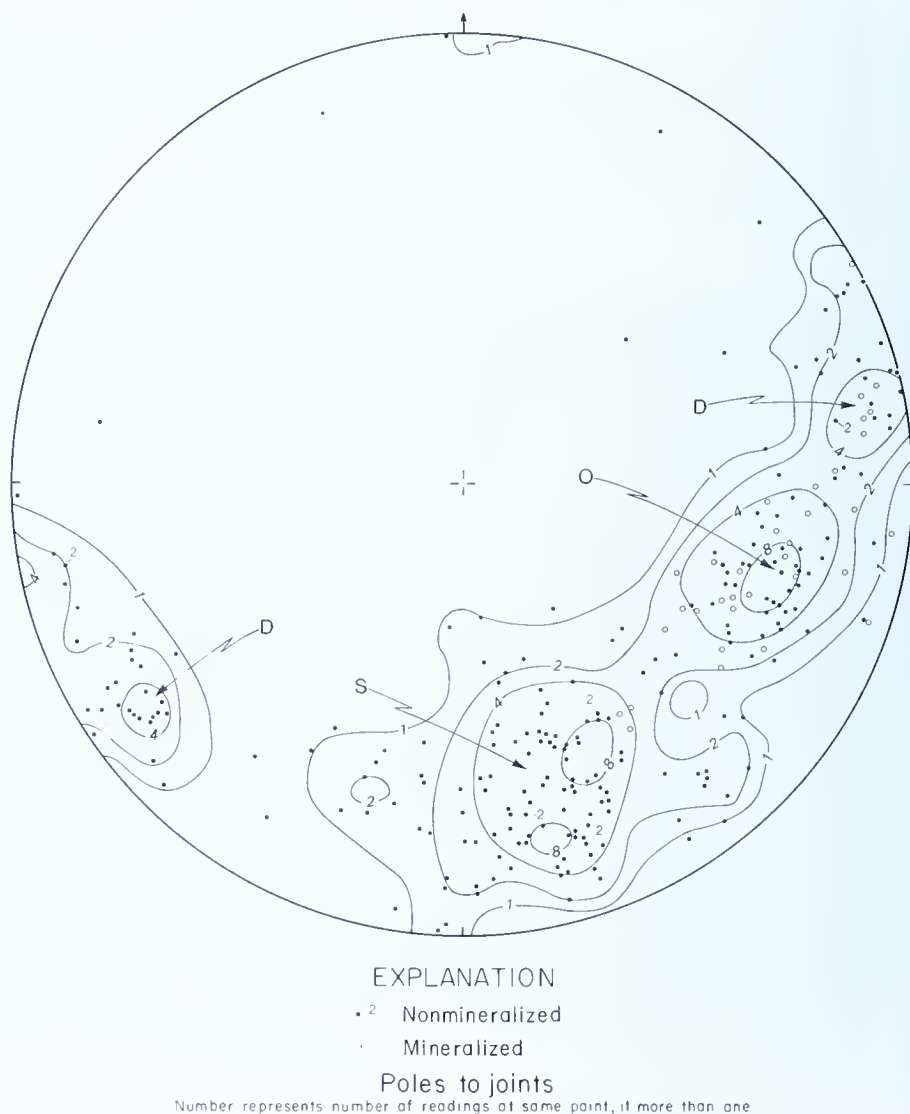


Figure 31. Stereogram (equal-area lower hemisphere projection) of 271 poles to joints on the south flank of the Milton anticlinorium. Dominant strike (S), dip (D), and oblique (O) sets are indicated by arrows. Contours are at 1, 2, 4, and 8 percent per 1-percent area.

Spacing of the joints within the sets depends to a great degree on the lithology and bedding thickness of the individual stratigraphic units. In the thick-bedded sandstones and conglomerates of the Pocono Formation, joints are commonly 0.3 to 2 m (1 to 7 ft) apart and occasionally as much as 6 m (20 ft) apart. Average joint spacing in most other units is 15 to 30 cm (0.5 to 1 ft), but separations of 5 cm (2 in.) or less are not uncommon in shaly intervals.

Approximately 15 percent of the joints in the report area are mineralized, there being a general tendency for dip and oblique joints to exhibit minerali-



Figure 32. Stereogram (equal-area lower hemisphere projection) of 411 poles to joints on the north flank of the Berwick anticlinorium. Dominant strike (S) and dip (D) sets are indicated by arrows. Contours are at 1, 2, 4, and 6 percent per 1-percent area.

zation more commonly than strike joints (Figures 31, 32, and 33). Joints in siliceous sandstones and siltstones are commonly filled with comb-like quartz veins or coated with fine quartz crystals. Such mineralization is especially characteristic of sandstones in the Centre Member of the Rose Hill Formation, the Moyer Ridge Member of the Bloomsburg Formation, and the Catskill Formation, and of siltstones and sandstones in the Trimmers Rock Formation. The limestones of the Tonoloway and Keyser Formations, on the other hand, often have solid calcite veins filling formerly open joints.

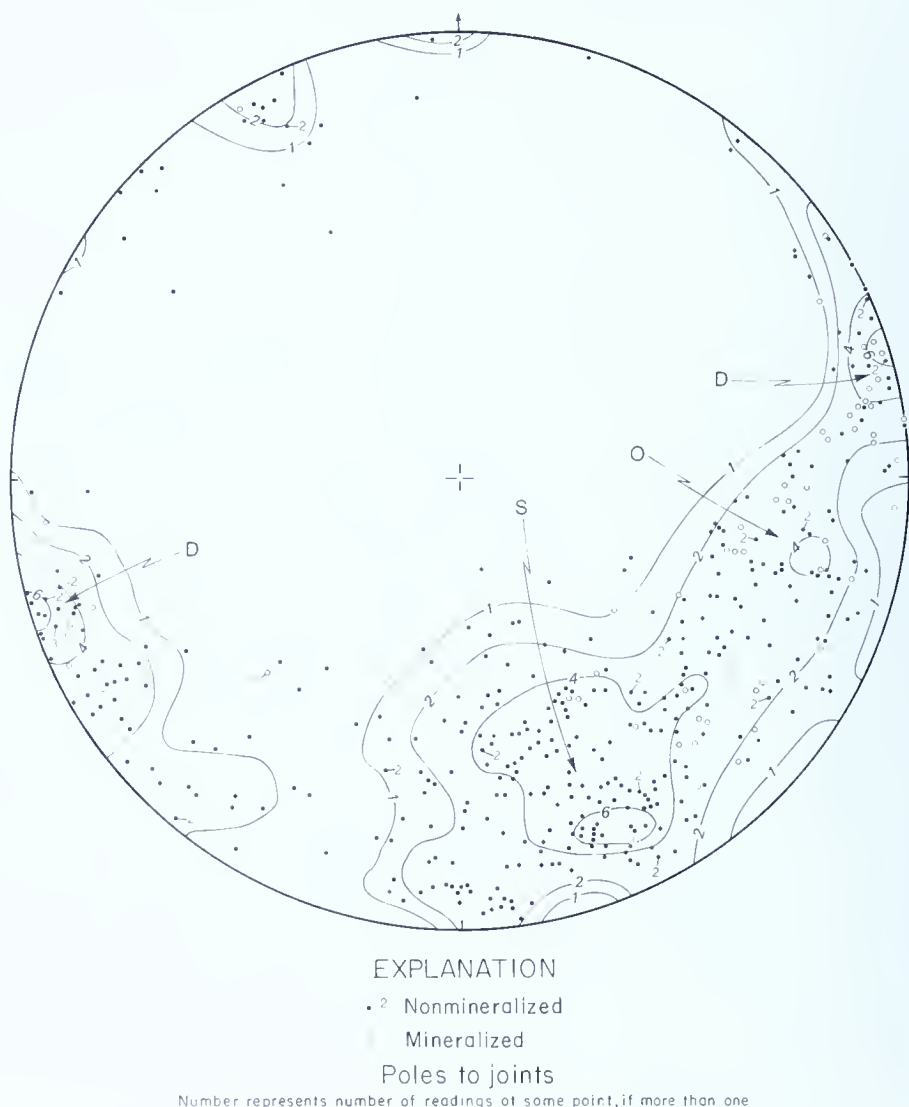


Figure 33. Stereogram (equal-area lower-hemisphere projection) of 461 poles to joints on the south flank of the Berwick anticlinorium. Dominant strike (S), dip (D), and oblique (O) sets are indicated by arrows. Contours are at 1, 2, 4, and 6 percent per 1-percent area.

ENVIRONMENTAL AND ENGINEERING GEOLOGY

The geologic framework of a region has a great influence on its cultural and economic development. Not only do direct material benefits accrue from abundant mineral resources or rich agricultural soils, but geologic factors commonly determine land use, transportation routes, and industrial development. Such environmental or engineering attributes as susceptibility to flooding and the stability, strength, and water-bearing characteristics of

the geologic materials affect the costs of all construction projects and may, in extreme cases, limit an area's economic growth.

With the exception of flooding, environmental constraints related to geology in the Bloomsburg-Mifflinville area are generally not critical. Even so, reasonable consideration must be given to the local geologic setting whenever engineering works of any kind (including single-family houses and water wells) are undertaken. The "Environmental Characteristics" legends of Plates 1 and 2 present a generalized evaluation of the cut-slope stability, difficulty of excavation, foundation strength and stability, and groundwater potential for each bedrock and surficial unit in the report area. Some specific observations bearing on these characteristics, as well as on the problem of flooding, are discussed below.

FLOODING

The flood-prone areas within the mapped quadrangles coincide with the areas delineated on the surficial geologic map (Plate 2) as alluvium, stony alluvium, alluvium and colluvium, undifferentiated, and alluvium and Olean outwash, undifferentiated. Generally these alluviated areas lie within 5 to 8 m (16 to 26 ft) of the normal low-water elevation on the Susquehanna River and Fishing Creek, and within 3 m (10 ft) on Briar Creek, Little Fishing Creek, and other secondary streams. Within the Susquehanna Valley, the major natural boundary of the flood-prone area is the riser between the low terrace-floodplain and the intermediate Olean outwash terrace.

Because of its high population density, the most critical flood-prone area is the broad, terraced Susquehanna River valley between Berwick and Bloomsburg. Major floods of the past century have all completely inundated the low-terrace/floodplain flats that border the river and have also swept through the depressed channelways that indent the intermediate terrace north of Almedia and Espy. Whereas most of Berwick lies above the river floodplain, a considerable portion of the town of Bloomsburg, including the airport, fairgrounds, Magee Carpet Mill, and extensive residential neighborhoods, is situated on the low terrace-floodplain within easy reach of floodwaters.

Fishing Creek and its tributaries are also subject to high flood crests. Because of the lesser development of high terraces along these streams, floodwaters may, in some areas, completely inundate the broad flats between steep valley walls. Both Orangeville and Light Street are built upon remnants of higher outwash terraces and are largely free of the threat of floods. However, the Fernville section of Bloomsburg and the northwestern part of Bloomsburg proper are severely affected by high water on Fishing Creek as well as by flood crests on the Susquehanna.

The severity of flooding on the Susquehanna River and Fishing Creek is the result of several physiographic influences, the most important of which

are the large drainage areas involved. The Susquehanna River above Bloomsburg has a drainage area of approximately $27,325 \text{ km}^2$ ($10,550 \text{ mi}^2$), and Fishing Creek drains an area of about $1,000 \text{ km}^2$ (386 mi^2) (U. S. Army Corps of Engineers, 1974). In addition, the deep incision of most streams in the North Branch basin, including Fishing Creek and its numerous tributaries, gives rise to a high rate of runoff during periods of prolonged rainfall. Runoff is further accentuated by the generally limited soil development on the summits and slopes of upland areas.

Within the present century, particularly destructive floods have struck the North Branch valley region in 1904, 1936, 1972, and 1975.¹ These four floods provide representative examples of the main causes of flooding in the Bloomsburg-Mifflinville area. The floods of January to March 1904 resulted in part from the occurrence of a tremendous ice gorge that blocked the North Branch from near Danville to Berwick, a distance of approximately 40 km (25 mi). At least three flood crests swept down the river before the ice gorge finally broke in March. Property damage and disruption of transportation were unprecedented; for example, at least six bridges, including those at Berwick, Mifflinville, and Catawissa, were carried away (see *Bloomsburg Press*, January to March 1904). The great flood of March 1936 was caused by a combination of snowmelt and prolonged seasonal rains. The June 1972 and September 1975 floods followed catastrophic rainfalls spawned by tropical storms Agnes and Eloise, respectively.

The heavy rainfalls that bring on floods and their attendant geologic effects—i.e., sedimentation and erosion—may also trigger slope failures and “washouts” far from the floodplains of streams. Some of the slope failures and debris flows described below were caused by the rainfall associated with the 1972 and 1975 floods.

SLOPES AND SLOPE STABILITY

The steepness of natural slopes in the Bloomsburg-Mifflinville area is related to both the erosional resistance of the bedrock units and the angle of repose of the mantling surficial materials. Except where structural attitude controls topographic configuration (as in the cove between Huntington and Lee Mountains), hard, highly indurated rocks such as quartzitic conglomerates, sandstones, and siltstones tend to form steeper terrain than easily weathered claystones and clay shales. Nearly all slopes in the area are subdued by surficial materials, particularly various types of colluvium. Ideally, the middle and upper portions of natural slopes are controlled by the erosional resistance of the underlying bedrock and the lower part by the angle of repose of colluvial materials. These slopes are normally stable under present conditions. Ciolkosz (in Marchand and others, 1978) notes

¹ Relative severity of these floods according to a stone monument near the Bloomsburg airport is, in order of decreasing magnitude: 1972, 1904, 1975, 1936.

that many colluvial slopes in central and eastern Pennsylvania may even be "super stable," having formed under the rigorous climatic conditions that prevailed in late Pleistocene time.

Slope problems in the report area are of two general types: (1) those that are related to runoff and erosion on steep slopes; and (2) those that are caused by instability of the geologic materials forming the slope. The first includes washouts, sheet flooding, and gulying on the steep natural slopes that exist on Knob, Lee, and Huntington Mountains and along deeply entrenched streams. Runoff from these slopes, even where they are heavily vegetated, may flood the basements of nearby homes or damage crops in adjacent fields. On the south side of Knob Mountain about 0.75 km (0.5 mi) east of Orangeville, and at the base of the steep scarp on the north side of the Susquehanna River 1.4 km (0.9 mi) northwest of Catawissa, landowners have constructed low dikes and shallow ditches to divert this slope runoff into nearby streams. An extreme example of slope runoff and its effects is evident in Stony Brook valley about 2.7 km (1.7 mi) northeast of Light Street, where concentrated runoff scoured a 2- to 3-m- (7- to 10-ft-) deep gully into colluvium and Trimmers Rock siltstone on the steep south wall of the stream valley. The material eroded from the gully was deposited as a poorly sorted, mound-like debris fan that temporarily blocked Stony Brook (Figure 34). Erosion of the gully and deposition of the fan appear to be results of a single catastrophic event which occurred during either the Agnes storm or the Eloise storm.

Slope problems caused by instability of geologic materials include many types of landslides and slope failures (Wilshusen, 1979). Materials on natural slopes in the report area generally become destructively mobile only during periods of exceptionally heavy rainfall. Excess water has several destabilizing effects on slopes, the most important being an increase in pore-water pressure that leads to a reduction of friction along discontinuities (bedding planes, joints, permeable zones, etc.) (Terzaghi, 1950). Silty and fine sandy slopes may also absorb so much water after heavy rains that they flow as a viscous mass; such flowage is especially common in the spring of the year when frost begins to melt out of the ground, leaving the surface soil saturated with water that cannot drain through underlying frozen materials. Probably the most destructive landslide noted in the report area occurred on a slightly modified slope at Fernville on the north side of Fishing Creek (41°00'05"N/76°28'06"W). At the height of the Agnes deluge, a combined debris and translational-rock slide in the Bloomsburg Formation dumped 10 to 12 truckloads of red shale across a secondary road and buried a travel trailer parked below. The existing scar, about 25 m (80 ft) wide and 5 m (16 ft) high, exposes soft, hackly to chippy, intensely mud cracked silty claystone that dips about 36 degrees to the southeast. The potential instability of the slope under the extremely wet conditions that prevailed at the time of the slide was probably increased by the soft and highly fractured nature of



Figure 34. Very poorly sorted debris fan composed of angular and sub-angular fragments of Trimmers Rock siltstone in a sandy silt matrix, on the south side of Stony Brook valley about 2.7 km (1.7 mi) northeast of Light Street ($41^{\circ}03'30''\text{N}/76^{\circ}24'18''\text{W}$). The head of the fan is visible in the background. The staff is 1.5 m (5 ft) long.

the bedrock and by slight undercutting of bedding along the base of the slope.

Many slope problems arise directly from human activities. The excavation of cut slopes to steeper angles than the natural slopes that have been relatively stable for hundreds, perhaps thousands, of years, commonly gives rise to instability of both bedrock and surficial materials. Such excavation often results in undercutting the toe of a natural slope, removing the natural buttress that maintained the integrity of the slope. Similarly, loading at the top (or head), either with an embankment or heavy structure, may cause failure of a previously stable slope.

Cut Slopes in Rock

Cut-slope stability in sedimentary rocks such as characterize the Bloomsburg-Mifflinville area depends primarily on (1) lithology, and (2) orientation, spacing, and roughness of discontinuities (bedding, joints, cleavage, and faults). To a large extent, other factors that affect stability of rock slopes, including depth and rate of weathering, and nature of groundwater flow, are related to these two physical attributes of the rock mass.

Clay shale and claystone content is the most significant lithologic factor controlling cut-slope stability in bedrock in this area. Both calcareous and noncalcareous clay shales and claystones are prone to rapid softening and loss of strength when exposed to atmospheric agents. Weathering of these rocks is due primarily to hydration of clay minerals, and, in the case of calcareous clay shales and claystones, leaching of carbonate cement. Whereas cuts in more durable rocks, such as siliceous sandstones and conglomerates (e.g., Pocono Formation) may stand at subvertical angles (76 degrees, or 1/4:1) for long periods of time without noticeable deterioration, steep cuts in initially hard, fresh shale (e.g., Wills Creek and Mahantango Formations) may become unstable through weathering within a few years. Especially critical are cut slopes in successions of interbedded durable and weak rock types such as siliceous sandstone and claystone (e.g., Catskill Formation), where weathering of the soft, clayey interbeds can lead to hazardous block falls in the more durable rock. Although topographic or economic considerations may dictate that steep slopes (greater than 45 degrees, or 1:1) be constructed in rock sequences having a large clay shale or claystone component, benches and rockfall zones should be provided to catch debris that may fall from the cut slope.

The orientation, spacing, and roughness of bedding planes, joints, cleavage, and faults is also critical in determining slope stability in rock cuts. Intersections of these discontinuities (particularly bedding and joints) form discrete blocks which may be unstable, particularly if the individual planes or their lines of intersection are undercut during excavation. If gravity stress can overcome the shearing resistance along these inclined surfaces, blocks or masses of rock will slip off the cut slope. Shearing resistance is increased by the relative roughness of the surface and decreased by excess water along the discontinuity. Most slope failures in jointed or otherwise fractured rock take place when high pore-water pressure reduces the angle of friction along the potential sliding surface. Closely spaced cleavage, bedding, and joint partings also cause an increase in the effects of frost riving and chemical weathering, especially in argillaceous and calcareous rocks.

One of the most important factors affecting cut-slope stability in bedrock is the relationship between the direction of the cut and the attitude of planar discontinuities, especially bedding. The three most common bedding-cut slope configurations encountered in highway and railroad cuts and quarries

in the report area are the following: (1) bedding strikes parallel or subparallel to the cut direction, dips out of the cut face at a moderate to steep angle, and is undercut by the excavation; (2) bedding strikes parallel or subparallel to the cut direction and dips into the slope; and (3) bedding strikes approximately perpendicular to the cut direction. Generally the first configuration gives rise to the greatest slope instability, as blocks may slide along bedding planes into the cut. The second and third configurations are typically less critical, but block failures of various kinds are still a potential problem (Figure 35).

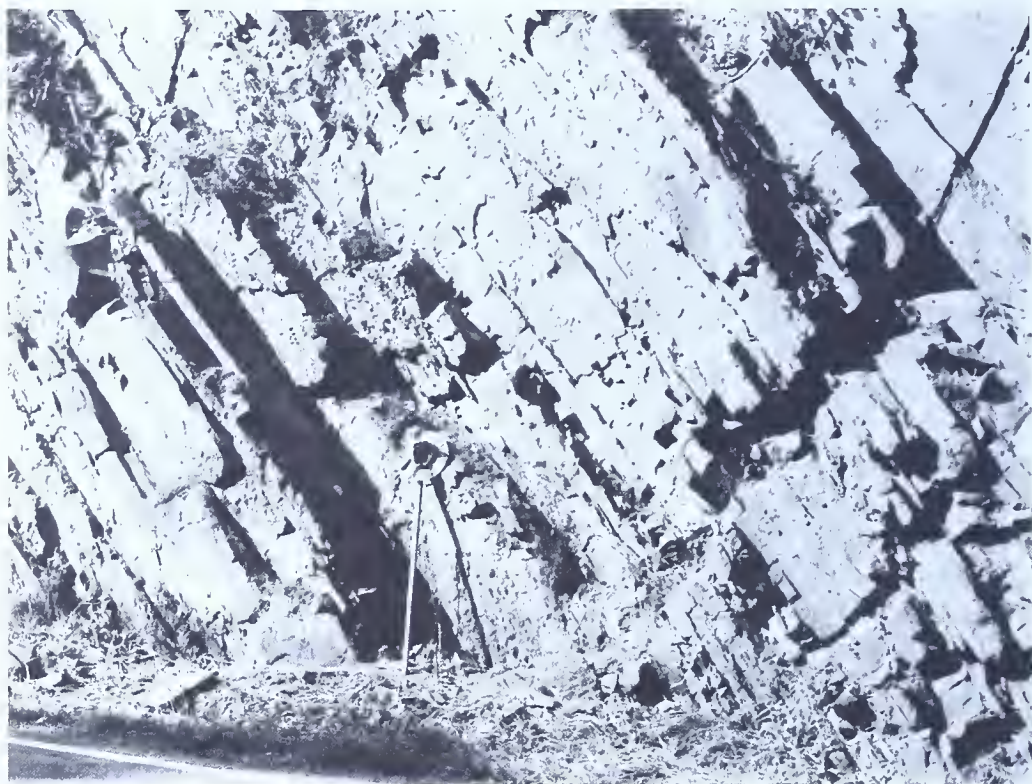


Figure 35. Cut slope in medium-bedded siltstone of the Trimmers Rock Formation, on the west side of Pa. Route 42, about 2.1 km (1.3 mi) northeast of Buckhorn ($41^{\circ}01'58''\text{N}/76^{\circ}28'57''\text{W}$). The strike of bedding is perpendicular to the cut, and the dip is toward the northwest. The face of the cut is roughly parallel to steep (80 degrees west) dip joints that are commonly open near the surface. These open joints bound overhanging slabs of rock that may topple onto the roadway. The staff is 1.5 m (5 ft) long.

Cut Slopes in Surficial Deposits

Under normal conditions, most vegetated cut slopes in surficial deposits are stable at angles up to about 25 degrees (2:1). Steeper cut slopes are sub-

ject to failure, particularly during or immediately following periods of heavy rainfall, and even low slopes must be protected by vegetation if long-term stability is required. The types of surficial cut-slope problems most prevalent in the report area include (1) gullying, (2) debris falls and slides, and (3) earthflows and shallow slumps. These are discussed below.

Severe gully erosion (1) is most common on cut slopes in thick, weakly cohesive, fine-grained materials such as glaciofluvial sands and loess. At the Light Street interchange of Interstate Route 80, two prominent gullies are developed in high cut slopes underlain by Muncy stratified drift. The affected slopes are inclined at about 30 degrees (1.8:1) and are covered with a thick growth of crown vetch. Gullying on the north side of the highway may have been caused by seepage of water from above a 4- to 7-cm- (1.6- to 2.8-in.-) thick band of sand cemented by black manganese oxide. The mineralized layer probably forms a nearly impervious seal that blocks infiltration of water further into the deposit. A high rate of seepage from above the manganese oxide band could have resulted in accelerated erosion of the underlying uncemented sands. Once erosion was initiated in this manner, continued seepage undermined the mineralized band and initiated headward erosion of the gully.

Cut slopes in Nescopeck Loess are even more susceptible to gullying than those in stratified sand and gravel. Several deep gullies in loess are present on the north side of the U. S. Route 11-Pa. Route 42 South interchange southwest of Bloomsburg (40°59'05"N/76°28'59"W).

The best example of a debris fall and slide (2) in the report area involves a high unstable slope in Glen Brook ice-contact stratified drift along Pa. Route 487 north of Light Street (Figure 36). The unstable slide area presently extends 96 m (315 ft) along the road and has a height of about 18 m (60 ft). At the top of the affected area is a 2-m- (7-ft-) high scarp from which bouldery debris periodically falls and slides downslope toward the road. Eastward retreat of this scarp due to debris fall has probably amounted to several meters and is likely to continue until the slope attains an inclination approximating the maximum angle of repose of the material. An 0.8-m- (2.6-ft-) high metal fence has been erected at the base of the slide to catch debris before it reaches the road.

Debris slides are also common springtime phenomena in the bouldery shale-chip rubble that blankets the steep western wall of the gap at Fernville (Figure 37). Generally at least one of these seasonal slides is large enough to cause partial blockage of the road below the slope.

Earthflows and shallow slumps (3) typically develop in silty and fine sandy deposits during spring thaw or rainy periods. Most occur in till, colluvium, or loess and are small enough to be only minor nuisances that require slight remedial work for correction. A typical example occurs in pre-Nescopeck loess on the north side of Legislative Route 19101, 1.8 km (1.2 mi) north-northwest of Lime Ridge (41°02'22"N/76°21'22"W).



Figure 36. Debris slide and fall in Glen Brook ice-contact stratified drift, on the east side of Pa. Route 487, 1.2 km (0.7 mi) north of Light Street ($41^{\circ}03'03''\text{N}/76^{\circ}25'43''\text{W}$). The bank, oversteepened by highway construction, is gradually receding through episodic collapse of the top of the scarp. The staff is 1.5 m (5 ft) long.

EXCAVATIONS

As a general rule, geologic materials can be divided into three groups based on increasing difficulty of excavation: (1) unconsolidated surficial deposits, including regolith; (2) moderately weathered or highly fractured bedrock; and (3) sound, moderately fractured to unfractured bedrock. Because this is also the vertical sequence of materials that is typically encountered in a deep excavation, it should be evident that some knowledge of the local geology is of considerable assistance in the successful completion of any excavation project.

Although most surficial deposits can be excavated using light power equipment, each deposit has its own peculiar excavation characteristics due to variations in grain size, clay content, and consolidation. For example,



Figure 37. Bouldery shale-chip rubble slope in the gap at Fernville, 1.0 km (0.6 mi) northwest of the Bloomsburg town square ($41^{\circ}00'34''\text{N}/76^{\circ}28'17''\text{W}$). Note the low piles of debris that have recently been pushed off the road.

moderate to deep excavations in till can generally be accomplished with a backhoe or relatively light crawler-tractor, but cuts in "hard pan" till may require use of a heavy tractor. Removal of oversize boulders in till poses special problems; boulders that cannot be moved aside by heavy equipment may have to be reduced to fragments by jackhammers or small explosive charges.¹ Loose gravels, sands, and silts are easily excavated with light equipment, but they are highly susceptible to caving if the walls of the excavation are not supported by artificial shoring. For this reason, narrow trenches for pipelines, sewerlines, or cables should always be advanced using a shield (Figure 38).

Excavations in nearly all types of weathered and/or intensely fractured bedrock can be completed with light to medium power equipment. Removal of fissile, highly cleaved or jointed rock (e.g., clay shales in the Rose Hill, Wills Creek, Mahantango, and Harrell Formations) can be most readily accomplished without blasting if excavation is carried out perpendicular to the major planar discontinuity (bedding, cleavage, etc.).

Although shallow excavations in sound, moderately fractured bedrock may locally be done using rippers or heavy crawler tractors, deep cuts will require blasting. Hard, thick-bedded quartzitic or hematitic sandstone and

¹ Boulders larger than 1 m (3 ft) in diameter are common in the Muncy and Glen Brook Tills, especially in Orange, North Centre, South Centre, and Scott Townships (see Plate 2) and in the boulder colluvium that mantles Knob, Lee, and Huntington Mountains.



Figure 38. Sewer-line trench in Nescopeck Loess on the north side of East 5th Street behind Scottown Plaza, 2.25 km (1.4 mi) east-northeast of the Bloomsburg town square ($41^{\circ}00'32''\text{N}/76^{\circ}25'58''\text{W}$). The excavation is about 2.5 m (8.2 ft) deep. The block-caving evident in the right foreground is typical of loess. Safe excavation of deep trenches in this unstable material was insured by use of a metal shield.

conglomerates, such as characterize the Pocono and Keefer Formations, the Centre Member of the Rose Hill Formation, and portions of the Catskill Formation, probably pose the most serious excavation difficulties.

FOUNDATIONS

Foundation conditions in the Bloomsburg-Mifflinville area are generally satisfactory and are likely to impose significant restraints on construction activity in only a few places. Except in the Susquehanna River and Fishing Creek valleys and in the till-choked valley south of Knob Mountain, relatively sound bedrock is close enough to the surface to be reached by most

foundation excavations. Even in those areas where bedrock does lie at considerable depth, the surficial materials are mostly compact gravels and tills that have bearing strengths suitable for medium structures. Some specific attributes and problems related to foundation conditions in bedrock and surficial deposits are discussed below.

Foundations in Bedrock

The probable foundation strength of the rock types that underlie the report area ranges from medium (clay shales and claystones) to strong (silty claystones, limestones and dolostones, and siliceous siltstones) and very strong (quartzitic sandstones and conglomerates) (see Attewell and Farmer, 1976). Within each individual rock type the bearing power may also vary by as much as 50 percent, depending on whether the load is imposed parallel to the dominant planar parting (bedding, cleavage, joints, etc.) or perpendicular to it; the latter is invariably higher (Legget, 1967). Although all bedrock units in the report area are strong enough to bear the weight of the heaviest structures likely to be built upon them, foundation problems may arise locally because of (1) bedrock disturbed by Pleistocene freeze-thaw activity and (2) pinnacle weathering and sinkholes in carbonate rocks.

In northeastern Pennsylvania, significant disturbance of bedrock by Pleistocene frost action is mainly confined to areas outside the Olean glacial border (Crowl and Sevon, 1980). Locally bedrock may be intensely fractured and contorted to depths of at least 1 m (3 ft), and on mountain crests exposed ledges may be disrupted at least 2 m (7 ft) below the surface. Because such frost-stirred rock is highly compressible and its distribution very irregular, structural foundations should always be set in sound rock below this zone (Legget, 1973).

Foundations in carbonate rocks commonly pose special problems because of the solubility of limestone and dolostone in mildly acidic groundwater. Since solution is irregularly concentrated along joint and bedding planes, the bedrock surface is typically characterized by pinnacles and isolated boulders of solid rock that are surrounded by deep pockets of reddish-orange silty clay. (The clay represents residual insoluble material that remains after leaching of carbonate from the limestone or dolostone.) Because clay is highly compressible and solid rock is obviously not, the first problem of construction in carbonate terrains is to insure that the foundation load is carried evenly to bedrock; otherwise, differential settlement may damage the structure.

An even more serious problem involving carbonate foundations is that of sinkholes. A sinkhole is a depression in the ground formed by natural subsidence related to the cavernous condition of the underlying rock. Although some sinkholes are caused by the actual collapse of the bedrock roof of underground caverns, most are believed to result from the caving-in of soil arches formed by the piping of silt-clay residuum into underlying solution

cavities (Foose, 1967). Instability of these soil arches is generally brought about by such changes in the hydrologic regime as alternate wetting and drying, long-term desiccation of a soil that is normally saturated, or extremely heavy rainfall.

Although no sinkholes are now known to exist in the Bloomsburg-Mifflinville area, the presence of a thick sequence of carbonate rock in the Tonoloway-Keyser interval raises the possibility that sinkholes could become a problem locally under certain conditions. Of the units mapped for this report, the Keyser Formation is apparently the most prone to solution, and the Tonoloway is a close second. Minor solution features were also observed in the Mifflintown Formation and the upper member of the Rose Hill, and their presence in the Onondaga Formation in the vicinity of Lime Ridge and Berwick cannot be discounted. Specific areas where extensive solution openings are known to occur in the Keyser Formation are in abandoned quarries on the grounds of the Berwick Golf Club at Martzville (Figure 39), in another abandoned quarry on a farm 0.9 km (0.6 mi) southwest of Martzville ($41^{\circ}03'48''\text{N}/76^{\circ}16'32''\text{W}$), and in the vicinity of the Poloron Products, Inc., plant, 1 km (0.6 mi) northeast of Lime Ridge ($41^{\circ}01'45''\text{N}/76^{\circ}20'49''\text{W}$).

Because of the widespread surficial cover in the region, problems with carbonate rocks will probably arise only in the construction of extremely



Figure 39. Small solution channel in limestone of the Keyser Formation, in an abandoned quarry on the grounds of the Berwick Golf Club at Martzville ($40^{\circ}03'54''\text{N}/76^{\circ}15'53''\text{W}$). The hammer is 28 cm (11 in.) long.

heavy structures, such as bridges, the foundations of which must be carried to fresh bedrock. In many areas, lighter structures can be founded on surficial materials, and, except in the rare cases where piping of sands into underground caverns could occur, the presence of carbonate bedrock is moot.

Hazardous conditions, somewhat similar to those related to sinks in carbonate terrain, may be caused by the underground "fossil-ore" mines within the outcrop belt of the upper member of the Rose Hill Formation. These old, nineteenth-century workings apparently rim Turkey Hill north and northeast of Bloomsburg and also wrap around the en echelon anticlinal noses on either side of Hemlock Creek (see Figure 47). Construction in areas that are within the old ore belt should be undertaken only after existing deep mines have been located and backfilled. A specific instance of the type of problem caused by these old workings was brought to the writer's attention by a local resident. When the grade of Iron Street was changed on the north side of Turkey Hill, 1.8 km (1.1 mi) north-northwest of the Bloomsburg town square (41°01'01"N/76°28'09"W), a large mine tunnel that ran east-west, perpendicular to the road, was encountered. Even though the tunnel was backfilled to road grade and the fill compacted, the presence of extensive cracking in the roadway indicates that settlement is still occurring at the site.

Foundations in Surficial Materials

Foundation strength and stability in the surficial deposits of the Bloomsburg-Mifflinville area depends primarily on the composition of the materials and the slope of the terrain on which they occur.

Except for such highly variable, waterlogged, or loosely consolidated deposits as alluvium, alluvium and colluvium, undifferentiated, and stony alluvium, most materials on flat or gently sloping ground provide suitable foundations for light structures. In many areas the Muncy and Glen Brook Tills appear to be sufficiently consolidated to support medium structures if bedrock lies too deep to be reached economically, but foundations for heavy structures should be carried to rock using piles or caissons. Even thick cobbly gravels such as characterize the Olean outwash and kame-moraine deposits should not be considered suitable for medium structures unless test holes show that buried compressible zones are not present within these vertically and laterally variable sediments. The channelways on the outwash terraces may be the sites of particularly questionable foundation materials, including clay lenses, organic muck, or even peat.¹

¹ The most impressive of these swampy, abandoned channels is the old "Espy bog," which once extended for approximately 1,400 m (4,600 ft) across the intermediate terrace north of Espy, but which is presently being filled in by developers. A large tract of open water south of U.S. Route 11 and west of Township Route 500 is the result of peat mining in the nineteenth and early twentieth centuries. According to DeVoe (1976), low-grade peat from this portion of the "bog" was initially used as fuel and soil conditioner and later was extensively utilized for filler in commercial fertilizers.

Steepness of slope is a limiting foundation condition affecting mainly colluvial and till deposits in upland areas. Because of the potential for gravitational sliding when the weight of even a light structure is imposed on sloping unconsolidated material, foundations in all moderately (5 to 15 degrees) to steeply (15 to 35 degrees) sloping areas should be set into solid rock. Building construction of any kind is generally impractical on slopes exceeding 35 degrees (1.7:1), even where bedrock is close to the surface.

GROUNDWATER

In the Bloomsburg-Mifflinville area, groundwater occurs in secondary fractures in bedrock and in primary intergranular pore spaces within saturated portions of the surficial deposits. Supplies of water adequate for domestic purposes can generally be obtained from bedrock within 60 m (200 ft) of the surface, but municipal and industrial wells may have to be drilled to depths of 120 m (400 ft) to obtain large yields even at favorable sites. The magnitude of the yield from individual bedrock wells depends to a great extent on such geologic factors as lithology, structure (number of fractures encountered), and topographic setting. Although surficial units in the report area commonly have low permeability and are generally too thin to yield significant amounts of water even for domestic purposes, adequate supplies can be obtained from saturated portions of the thick alluvial and Olean glaciofluvial deposits of the Fishing Creek and Huntington Creek valleys upstream of Orangeville. In the Susquehanna Valley, some wells drain water from fractures in bedrock as well as from a thin saturated section of Olean outwash gravel directly overlying bedrock (J. H. Williams, personal communication). Generalized groundwater information for the various bedrock and surficial units is given under "Environmental Characteristics" on Plates 1 and 2.

A detailed report on the groundwater resources of central Columbia County (including the Bloomsburg and Mifflinville quadrangles and the northwestern portion of the Catawissa quadrangle) is currently being prepared by J. H. Williams of the U. S. Geological Survey, Water Resources Division.

MINERAL RESOURCES

The Bloomsburg-Mifflinville area has a history of industrial and metallic mineral production that dates back more than a century. Although only sand and gravel and crushed stone are currently produced within the report area, clay shale, limestone, particulate anthracite coal, zinc and lead ores, and iron ore were at one time or another targets of significant commercial development. Although past exploitation and recent urbanization have removed large areas from the potential resource base, enough sand and grav-

el, crushed stone, and clay shale could be produced to satisfy demand far into the future. Considerably less potential exists for the production of limestone, lead and zinc ores, iron ore, and particulate coal. Uranium and oil and natural gas can be considered at this time only as possible resources. Awareness of the location and nature of the known mineral resources, such as sand and gravel, should aid in planning the future expansion and development of the area.

SAND AND GRAVEL

Sand and gravel is the most important mineral resource in the report area in terms of both current production and economic reserves. Large quantities of material suitable for many industrial and commercial applications are available in the alluvial, glaciofluvial, and morainal deposits that border the Susquehanna River, Fishing Creek, and Huntington Creek.

Geologic factors that determine the economic value of sand and gravel resources are: (1) areal extent and thickness of the deposits; (2) size, sorting, and shape of the clasts; (3) lithology of the clasts; and (4) degree of weathering of the clasts. Economic and social factors that must also be considered include distance and mode of transport, and current land use patterns.

(1) Sand and gravel deposits of sufficient areal extent and thickness for commercial exploitation are present along nearly the entire length of Fishing and Huntington Creeks and the Susquehanna River. The widest and thickest belts of stratified material occupy northeast-southwest-trending portions of the major stream valleys (Plate 2). These wide valley reaches were eroded along the strike of relatively soft rock units and contrast sharply with the narrow valleys cut transverse to rock structure. Thickness of stratified deposits in the favorable strike valleys ranges from less than 3 m (10 ft) in the Olean low terrace/floodplain deposits along the Susquehanna River to more than 25 m (82 ft) in the Olean high terrace at Mifflinville and the Olean kame moraine downstream of Jonestown. Alluvial and outwash sediments in the Fishing Creek valley northeast of Orangeville and west of Light Street locally exceed 12 m (39 ft) in thickness. Because many of these areas are also prime sites for commercial, residential, agricultural, and industrial development, however, only a small portion of the total land area underlain by large deposits of sand and gravel can be seriously considered as having a potential for extractive operations.

(2) Grain size, sorting, and shape of clasts differ considerably between and within the various types of alluvial and glaciofluvial deposits. Beds typically range from poorly sorted, cobbly and bouldery gravel containing a relatively insignificant sand matrix to moderately well sorted, fine to coarse sand. Such textural differences generally occur within a few meters of vertical distribution.

Grain size distribution curves for eleven sand and gravel samples are shown in Figures 40 and 41. The samples from the Susquehanna Valley con-

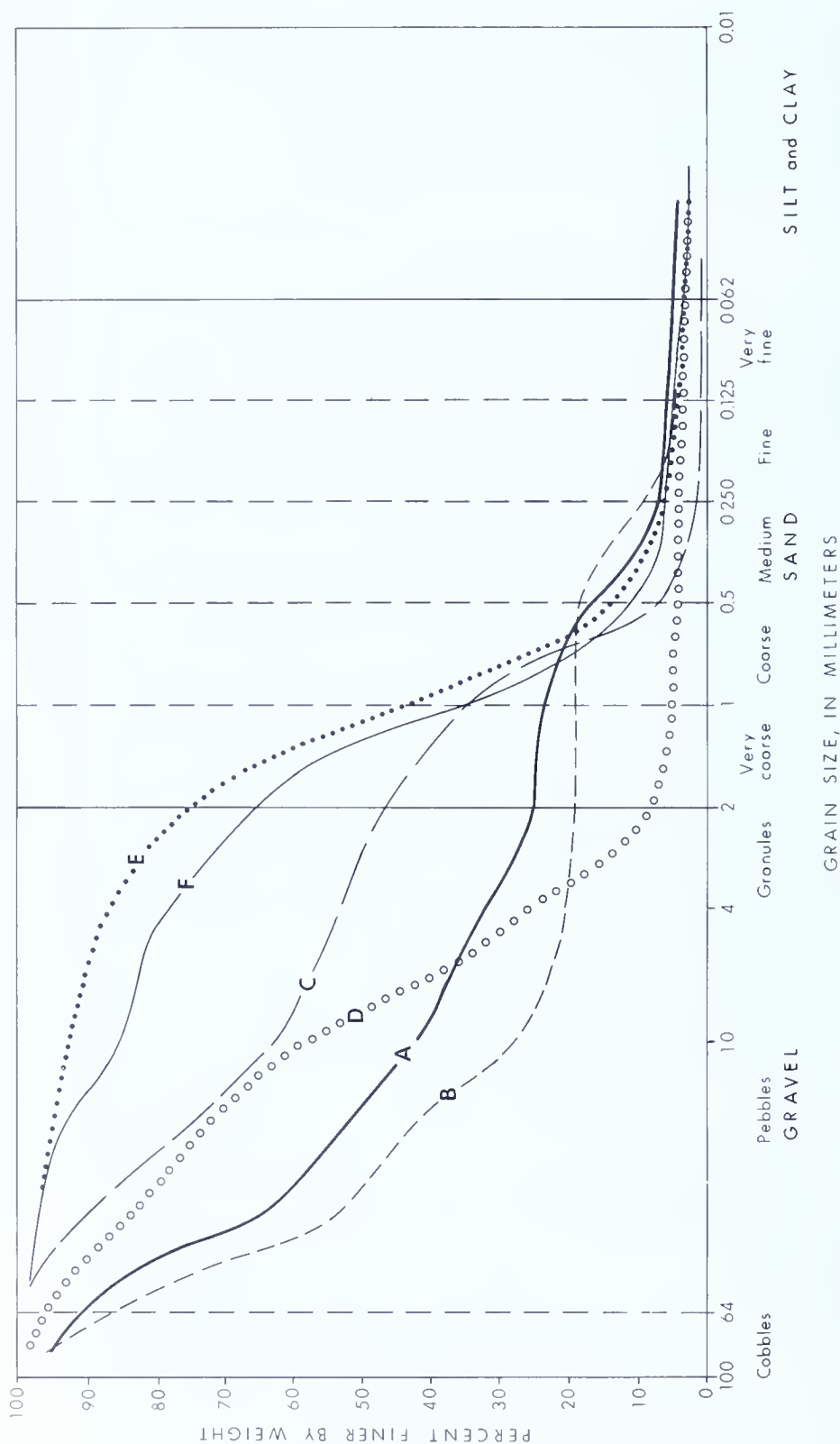


Figure 40. Grain size distribution curves of sand and gravel samples from the valley of the North Branch of the Susquehanna River (A = Olean outwash, intermediate terrace; B to F = Olean outwash, high terrace).

A. Abandoned pit at the west end of Maple Road, in the southwestern portion of Berwick borough ($41^{\circ}02'37''N/76^{\circ}16'10''W$).

B. Abandoned pit on the south side of Pa. Route 339, about 3.2 km (2 mi) east of Mifflinville ($41^{\circ}02'10''N/76^{\circ}15'51''W$).

C. Abandoned pit near the contact between the Olean and the Berwick terraces, about 1.3 km (0.8 mi) west-northwest of Catawissa ($40^{\circ}57'17''N/76^{\circ}28'43''W$).

D. Abandoned pit at the American Legion Post, 1 km (0.6 mi) northwest of Catawissa ($40^{\circ}57'21''N/76^{\circ}28'24''W$).

E and F. Abandoned pit about 125 m (410 ft) north of Legislative Route 19025, 1.3 km (0.8 mi) west-northwest of Catawissa ($40^{\circ}57'17''N/76^{\circ}28'43''W$).

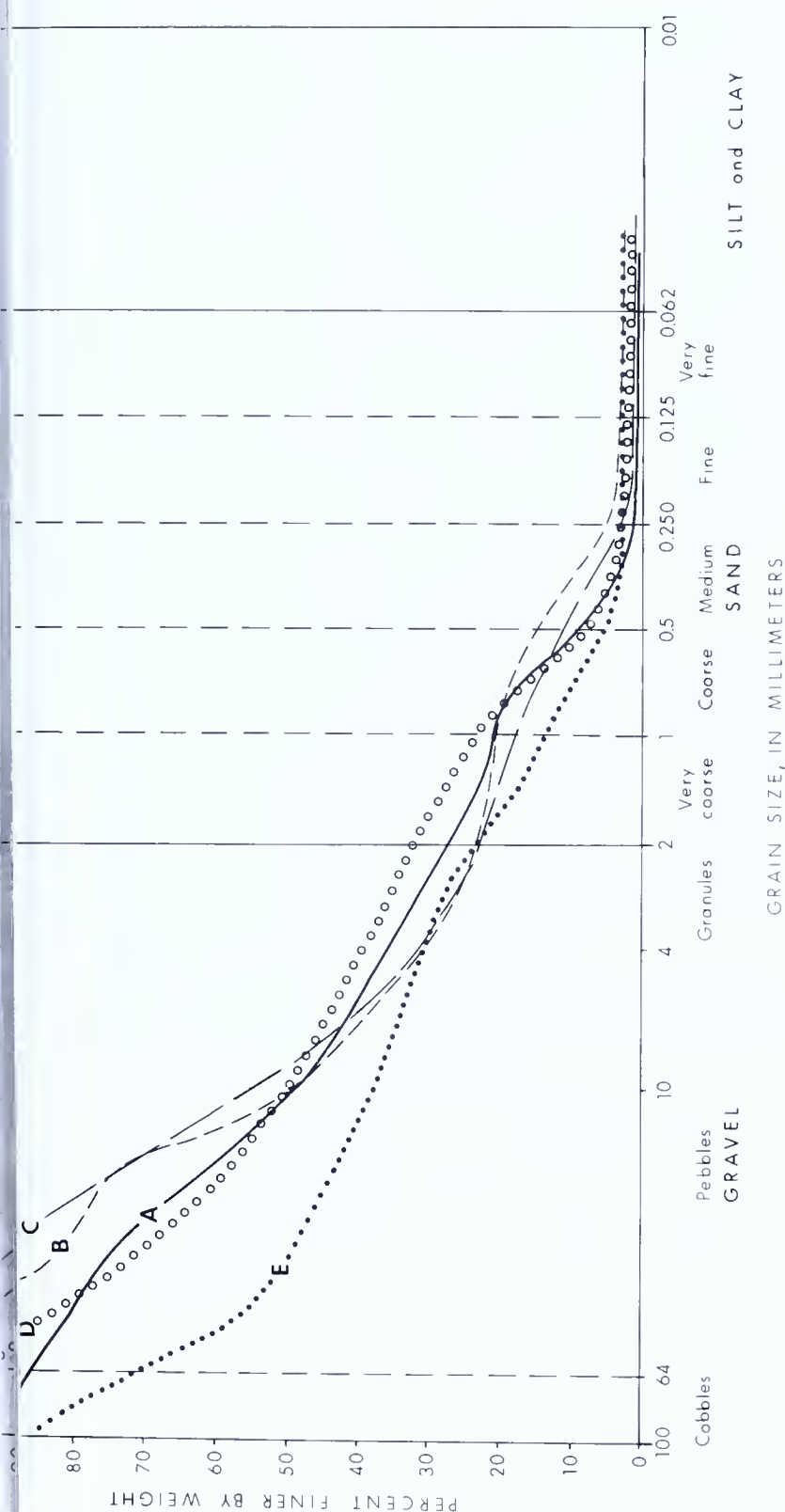


Figure 41. Grain size distribution curves of sand and gravel samples from Fishing Creek and Huntington Creek valleys (A to C = alluvium and Olean outwash, undifferentiated; D = Olean outwash; E = Olean ice-contact stratified drift).

A. Diversion ditch on the south side of Fishing Creek valley, 2 km (1.2 mi) northeast of Orangeville (41°05'34"N/76°23'50"W).

B and C. Dredging area (east end) of the Bloomsburg Sand and Gravel Company, on the south side of Fishing Creek valley, 0.2 km (0.1 mi) west of Light Street (41°02'06"N/76°25'36"W).

D. Abandoned pit on the north side of Legislative Route 19031 near the U. S. Geological Survey gaging station, 1.1 km (0.7 mi) west of Orangeville (41°04'41"N/76°25'44"W).

E. Abandoned pit in an esker on the north side of Huntington Creek, about 1 km (0.6 mi) southwest of Jonestown (41°07'28"N/76°18'46"W).

tain from 20 to 90 percent gravel, 7 to 75 percent sand, and 1 to 5 percent silt-clay, whereas those from the Fishing Creek-Huntington Creek valley contain 65 to 85 percent gravel, 20 to 34 percent sand, and 1 to 3 percent silt-clay. Samples collected closer to the former Olean ice border (further upstream) in both areas have a tendency to be coarser and more poorly sorted (Figure 40A, B; Figure 41E).

Most of the pebbles and cobbles are well rounded and range in shape from roughly spherical to discoidal and platy. The abundance of nonspherical clasts in deposits along Fishing Creek reflects the large amount of sandstones and siltstones derived locally from the thin- to medium-bedded Trimmers Rock and Catskill Formations. Boulders and large cobbles in the kame moraine and ice-contact stratified drift are frequently subrounded to subangular.

The alluvial and glaciofluvial deposits locally contain thick accumulations of very fine to medium-grained, moderately well sorted sand that are relatively free of coarse clasts (Figure 42). The largest of these deposits fills a part of Fishing Creek valley on the north side of Turkey Hill and is utilized by the Bloomsburg Sand and Gravel Company as a source of sand. The deposit, which occurs at the same elevation as the Olean outwash terrace at Light Street and is presumably part of this same valley train, consists of rippled, fine- and very fine grained sand that contains thin, widely separated beds rich in small, platy shale fragments.

(3) Clast lithology in the sand and gravel deposits is diverse and includes material of both local and distant origin (Figure 43). About 85 to 95 percent of the pebbles and cobbles are derived from rock that crops out in the report area or immediately to the northeast. By far the most abundant lithology is olive-gray to medium-gray, very fine to fine-grained sandstone from the Trimmers Rock and Catskill Formations. Deposits in the Susquehanna River valley clearly contain a greater diversity of lithologies than those in the Fishing Creek-Huntington Creek valley. Exotic quartzite, chert, and metamorphic igneous rock fragments are relatively common in the former, but are virtually absent in the latter.

Generally the clasts are of hard, durable lithologies and are relatively free from fractures. Soft and fissile claystone and clay shale constitute less than 2 percent of all samples in the Susquehanna Valley, but make up 6 to 8 percent of two samples in the Fishing Creek-Huntington Creek valley. Therefore, the Susquehanna River gravels are somewhat superior in quality to those along its main tributary system. Sand and gravel along the river, however, contains a different deleterious substance—anthracite coal. Although the amount of coal in the outwash and alluvial sediments generally is not a significant problem, enough coal is probably present in the outwash gravels in the southwest corner of the mapped area (opposite the mouth of Catawissa Creek) to seriously detract from their usefulness as an aggregate source.

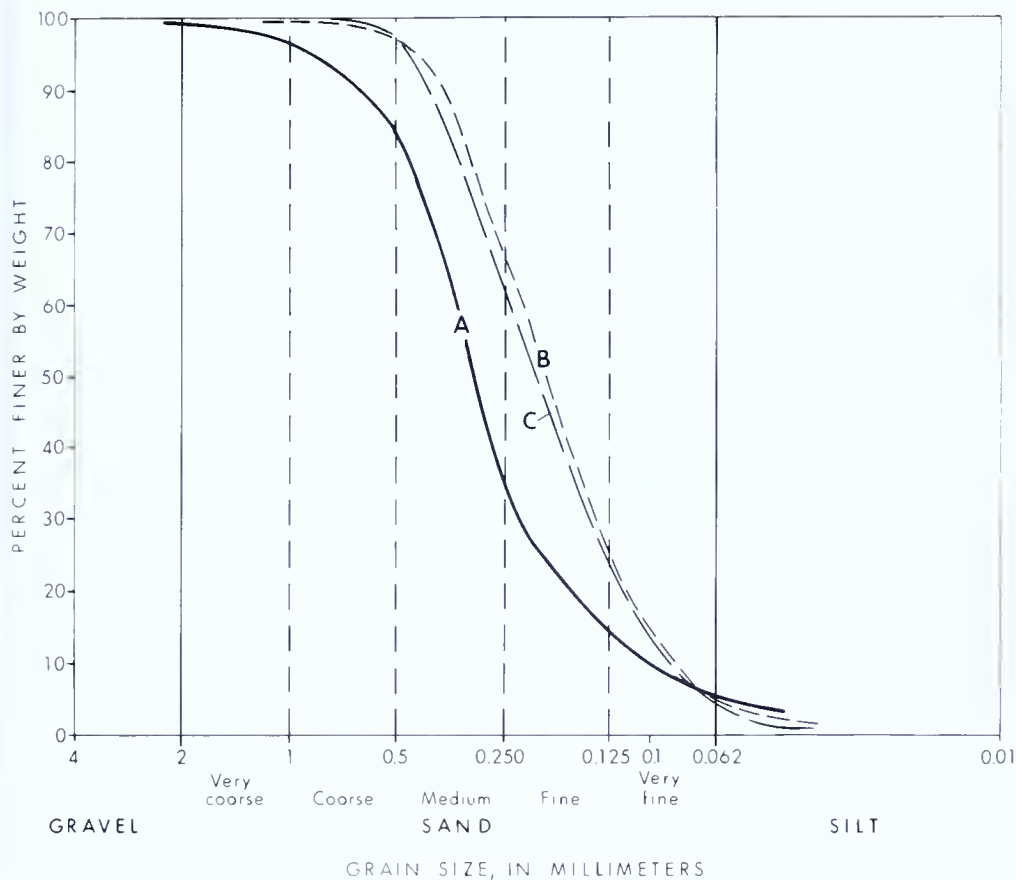


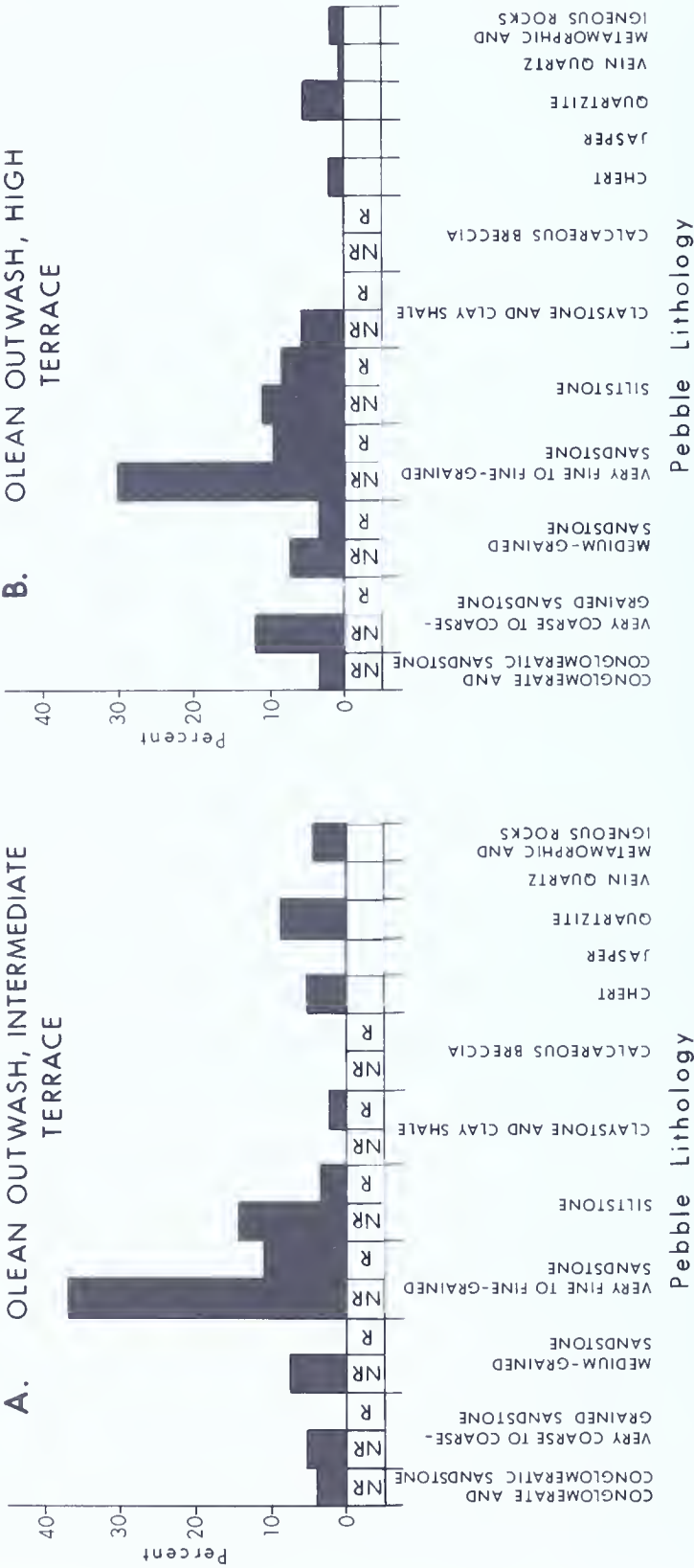
Figure 42. Grain size distribution curves of sand samples from Fishing Creek valley (A = alluvium and Olean outwash, undifferentiated; B and C = Olean outwash).

A. Diversion ditch on the south side of Fishing Creek valley, 2 km (1.2 mi) northeast of Orangeville ($41^{\circ}05'34''\text{N}/76^{\circ}23'50''\text{W}$).

B and C. Sand pit of the Bloomsburg Sand and Gravel Company, on the south side of Interstate Route 80, 0.6 km (0.4 mi) southeast of Paper Mill ($41^{\circ}01'32''\text{N}/76^{\circ}26'10''\text{W}$).

The sand fraction of the deposits is composed predominantly of lithic grains and quartz; the percentage of lithic fragments decreases from about 75 percent in coarse-grained sand to about 25 percent in very fine grained sand. Magnetite is quite abundant in the fine- and very fine grained sand fraction. Considerable fine-grained particulate coal is also present in sands along the Susquehanna River.

(4) Although most of the clasts in the alluvial and Olean glaciofluvial sand and gravel deposits are relatively fresh, the presence of weathered clasts derived from two different sources is significant. Some soft, weathered siltstone and sandstone clasts are undoubtedly derived from older glacial drift (Muncy and Glen Brook). More importantly, the upper 3 to 7 m (10 to 20 ft) of Olean outwash and ice-contact deposits is leached and oxi-



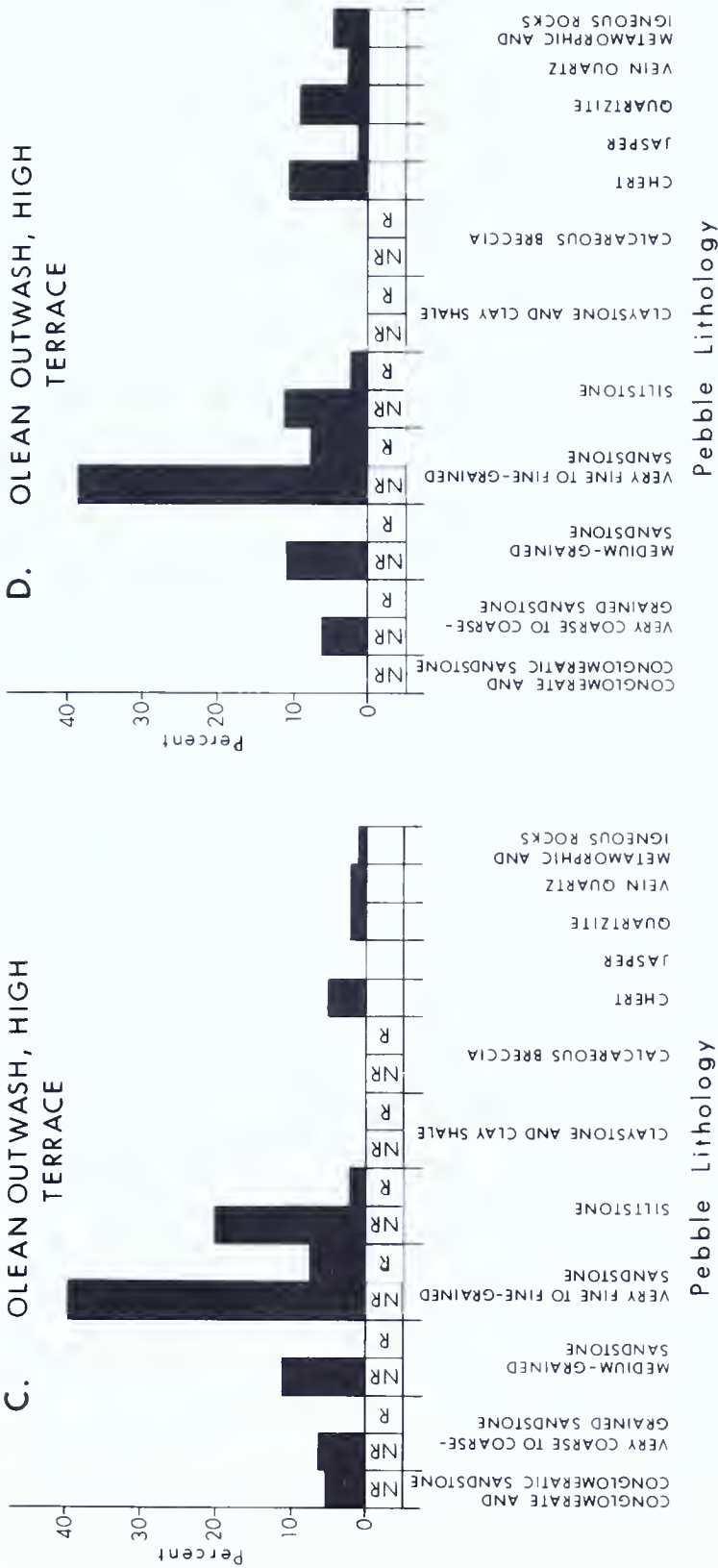
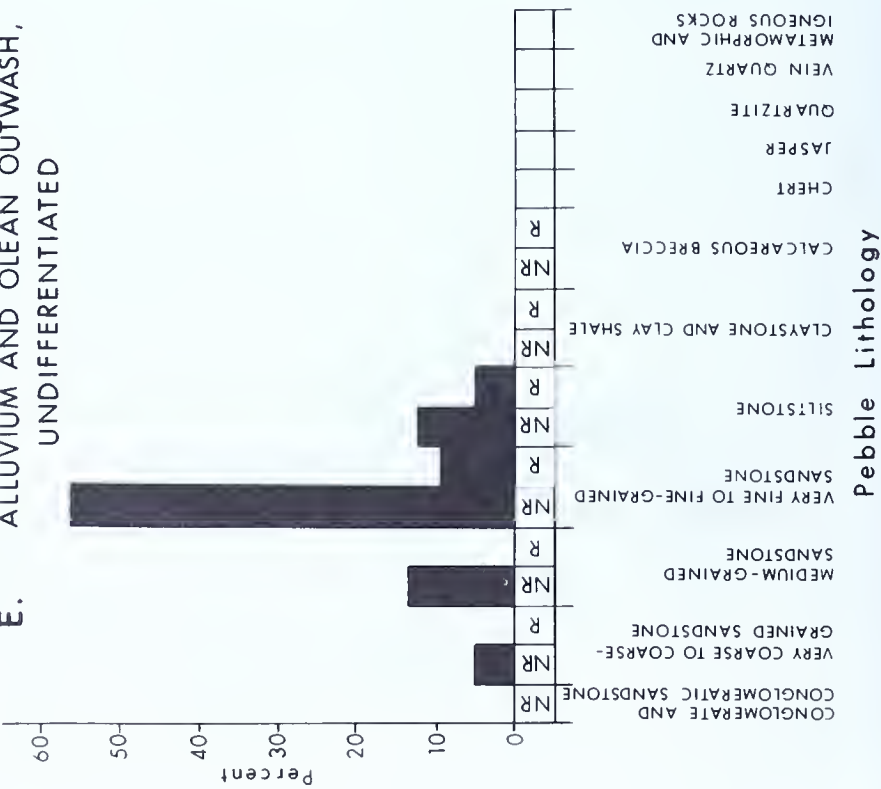
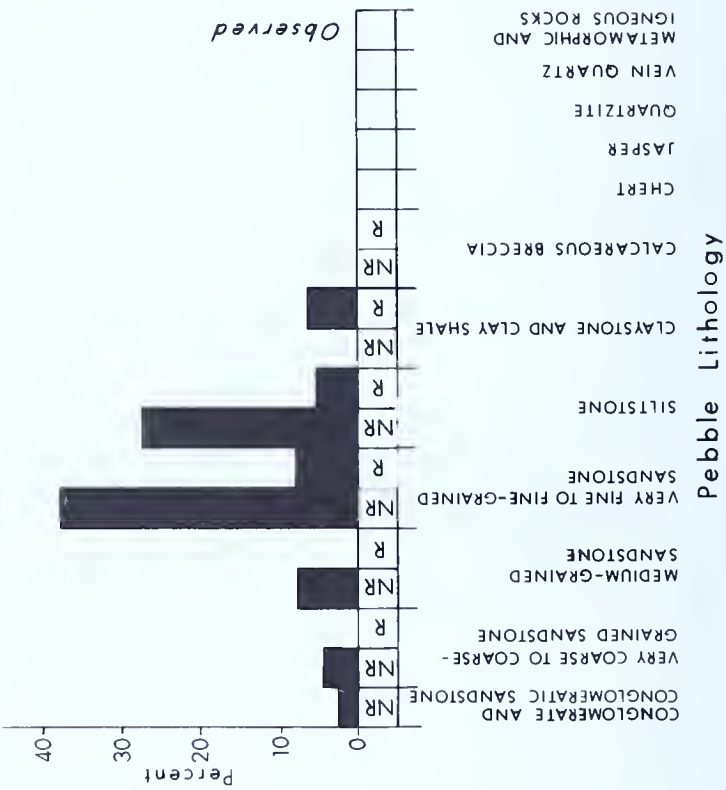


Figure 43. Histograms showing the lithologic composition of some sand and gravel deposits in the Bloomsburg and Mifflinville quadrangles. Based on identification of 100 pebbles in the 1.0- to 3.0-cm (0.4- to 1.2-in.) size fraction (NR = nonred; R = red).

E. ALLUVIUM AND OLEAN OUTWASH, UNDIFFERENTIATED



F. OLEAN OUTWASH



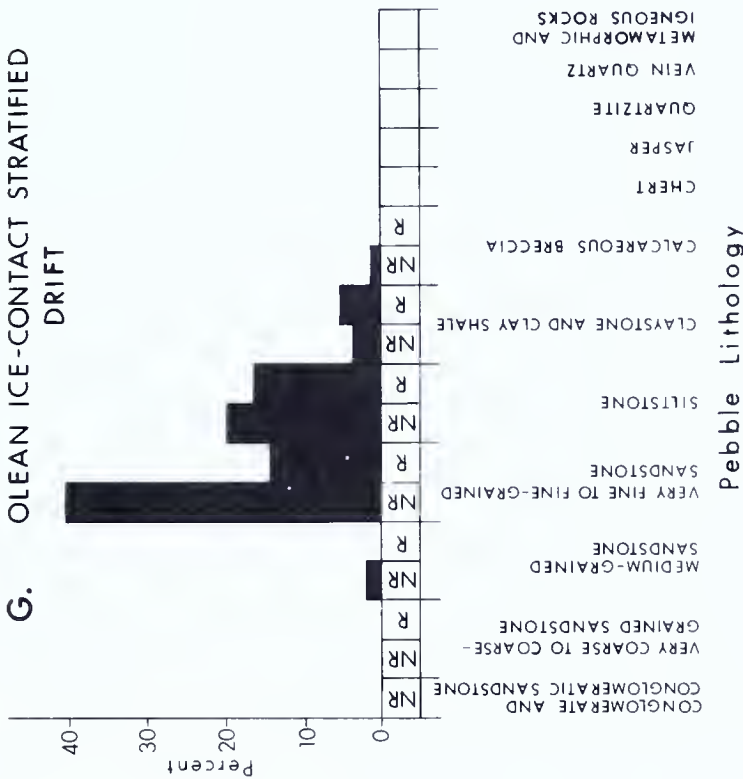


Figure 43. (Continued)

- A. Abandoned pit at the west end of Maple Road, in the southwestern portion of Berwick Borough (41°02'37"N/76°16'10"W).
- B. Abandoned pit on the south side of Pa. Route 339, about 3.2 km (2 mi) east of Mifflinville (41°02'10"N/76°15'51"W).
- C. Abandoned pit near the cemetery about 150 m (500 ft) east of Mifflin Township Route 640 in Mifflinville (41°01'47"N/76°18'15"W).
- D. North side of U. S. Route 11, 215 m (700 ft) west of the Tennytown Motel, about 4.3 km (2.7 mi) east-northeast of the Bloomsburg town square (41°00'46"N/76°24'34"W).
- E. Dredging area (east end) of the Bloomsburg Sand and Gravel Company, on the south side of Fishing Creek valley, 0.2 km (0.1 mi) west of Light Street (41°02'06"N/76°25'36"W).
- F. Abandoned pit on the north side of Legislative Route 19031 near the U. S. Geological Survey gaging station, 1.1 km (0.7 mi) west of Orangeville (41°04'41"N/76°25'44"W).
- G. Abandoned pit in an esker on the north side of Huntington Creek, about 1 km (0.6 mi) southwest of Jonestown (41°07'28"N/76°18'46"W).

dized, and certain lithologies—especially limestones, calcareous siltstones, and argillaceous sandstones—may exhibit considerable alteration (Peltier, 1949). Therefore, removal of this weathered-zone material prior to crushing will greatly improve the quality of the aggregate produced (Craft, 1979). Depth of weathering is less in the alluvium and Olean outwash, undifferentiated, deposits; hence, secondary alteration poses a less serious threat to aggregate quality.

The Bloomsburg Sand and Gravel Company, the only sand and gravel producer that is presently active in the report area, operates two plants in the vicinity of Light Street. Plant No. 1 is situated on the gravel terrace north of Interstate Route 80, and Plant No. 2 is located south of the highway at the sand pit formerly owned by Frank Whitenight, Inc. Current production is mainly from large dredge pools in the alluvium and Olean outwash, undifferentiated, about 0.8 km (0.5 mi) west of Light Street. These deposits form a wide, triangular-shaped floodplain 0.7 km (0.4 mi) wide at its maximum. The thickness of the sand and gravel beneath this area ranges up to about 12 m (40 ft), 6 to 8 m (20 to 26 ft) of which lies below stream level. Although the sand from the pit at Plant No. 2 is too fine grained for many purposes, it is mixed with aggregate and sand from the dredge pools to make satisfactory products. The total thickness of sand in the pit is approximately 8 m (26 ft).

Commodities produced by the Bloomsburg Sand and Gravel Company include Pennsylvania Type A gravel (mainly 2A and 1B coarse aggregate), Type A fine aggregate, concrete and mason's sand, drain-field sand for septic systems, and general fill. The coarse aggregate has an E (excellent) skid-resistance level (SRL) according to Pennsylvania Department of Transportation (PennDOT) standards and has no limitations on use as a highway construction material.

CRUSHED STONE

Since the late 1960's the Columbia Asphalt Company (Clair C. Hock, Inc.) has produced crushed stone for construction purposes from a large quarry in the Sherman Creek Member of the Catskill Formation about 0.5 km (0.3 mi) south of Mordansville (Figure 44). The dominant lithology in the quarry consists of medium-bedded, grayish-red, calcareous siltstone and silty claystone containing thin to medium interbeds of blocky, micaceous, very fine grained, grayish-red sandstone. Some olive-gray to medium-light-gray, fine-grained sandstone beds crop out along a haul road at the north edge of the property. Bedding in the quarry generally dips 12 to 20 degrees southeastward, except where small kink-band flexures cause local steepening of the dip to as much as 45 degrees.

Both Type A coarse aggregate and Type B (bituminous only) fine aggregate (PennDOT specifications) are produced from the quarry. The coarse



Figure 44. Crushed stone quarry of the Columbia Asphalt Company, 0.6 km (0.4 mi) south-southeast of Mordansville (41°03'42"N/76°29'46"W).

aggregate, mostly 2A and 1B stone, has an H (high) SRL and is used extensively for bituminous paving of primary and secondary roads in the local area.

The Mordansville quarry is situated on a prominent ridge west of Fishing Creek and was originally opened on the south (dip) slope of the hill. As excavation was carried to the north, the south-dipping beds were soon seriously undercut and a potentially unstable highwall was created. Before any disastrous consequences ensued, the operators moved around to the east end of the property and commenced quarrying in a westerly direction (approximately parallel to bedding strike). The danger of rock slides was thus greatly reduced (Clair Long, personal communication).

Other rock units in the report area that would probably serve as satisfactory sources of crushed stone are the Keyser and Tonoloway Formations (limestone), the middle portion of the Trimmers Rock Formation (siltstone and sandstone), some sandstones of the Duncannon Member of the Catskill Formation, and conceivably the Pocono Formation. Utilization of these materials would be most feasible on construction projects that would require large-scale excavation in that particular rock unit, allowing the stone to be crushed and used near the site of excavation.

CLAY SHALE

Clay shale is used in the manufacture of a wide variety of products, including structural clay products, pottery, lightweight aggregate, and refrac-

tories. In the mapped area, clay shales and claystones constitute nearly the entire thickness of the Bloomsburg, Marcellus, Mahantango, and Harrell Formations, and significant portions of the Rose Hill, Mifflintown, Wills Creek, Old Port, Onondaga, Trimmers Rock, and Catskill Formations. Past production has been mainly from the Harrell and Bloomsburg Formations; the Alliance Clay Products Company formerly used shale from these formations to manufacture bricks at a large works about 1.7 km (1.1 mi) east of Mifflinville. This operation, consisting of five kilns, was active from at least 1952 to 1965. Bricks were manufactured from a blend of gray Harrell shale (obtained from pits just southeast of the works) and red Bloomsburg shale (obtained from a pit along U. S. Route 11 near Willow Springs). J. L. Turner and Company also operated a brickyard at Mifflinville in the 1930's (Leighton, 1941).

Ten samples were collected from various stratigraphic horizons in the report area and were tested by the U. S. Bureau of Mines for their ceramic and other properties (Table 1; Appendix 2). These preliminary analyses indicate that all of the sampled shales have some potential for the manufacture of structural clay products and that several may prove suitable for lightweight aggregate production upon further testing.

Structural Clay Products

All of the samples tested for ceramic properties have short workability and are suitable only for products made using the soft-mud and dry-press processes. These processes are used in the manufacture of building brick, floor brick, and facing brick and tile. A single sample (no. 1) from the Catskill Formation has suitability for building brick at 1100 to 1200°C (2000 to 2200°F) and for floor brick at 1150 to 1200°C (2100 to 2200°F). The material possesses a wide firing range and a pleasing strong-brown to orangish-brown baked color, and is hard to very hard. Two samples (nos. 2 and 3) from the Harrell Formation show rather dissimilar properties, although both are suitable for making building and floor brick and facing tile. A sample (no. 3) from the old Alliance Clay Products Company pit at Mifflinville shows good fired color and very high hardness throughout the firing range. The lower member of the Mahantango Formation (nos. 4–7, inclusive) has potential for use in the manufacture of building and floor brick, mostly within the firing range of 1100 to 1150°C (2000 to 2100°F). The presence of numerous calcareous zones in the member, however, may limit its usefulness for structural clay products. Single samples from the Onondaga and Bloomsburg Formations (nos. 8 and 9, respectively) and the lower member of the Rose Hill (no. 10) also exhibited good potential for building and floor brick, particularly in the range 1100 to 1500°C (2000 to 2100°F). The presence of calcium carbonate in the Onondaga may pose some difficulties, however.

Table 1. *Ceramic Properties of Clay Shales*¹

Sample number	Formation ²	Latitude and longitude	Water of plasticity				Drying shrinkage (percent)	Dry strength	pH	Effervescence with HCl	Bloating test ³	Vitrification temperature (°C)
			Color	Plasticity	Drying defects (percent)	Drying shrinkage (percent)						
1 (174c-5)	Desc	41°00'28"N 76°14'35"W	Brown	Short	20.4	None	0.0	Good	5.5	None	N	1200-1250
2 (164c-4)	Dh	41°06'26"N 76°28'37"W	Gray	Short	17.8	None	2.5	Fair	6.5	None	N	1150-1200
3 (164d-1)	Dh	41°01'46"N 76°16'45"W	Dark gray	Short	14.8	None	0.0	Good	5.1	None	N	1150-1200
4 (164c-1)	Dml	41°06'34"N 76°28'45"W	Gray	Short	15.8	None	2.5	Poor	7.5	None	P	1150-1200 Expanded
5 (164c-2)	Dml	41°07'28"N 76°25'08"W	Gray	Short	14.2	None	2.5	Poor	8.2	None	P	1150-1200 Expanded
6 (164c-3)	Dml	41°02'25"N 76°25'52"W	Gray	Short	12.1	None	0.0	Poor	8.0	Slight	P	1100-1150 Expanded
7 (164d-2)	Dml	41°03'49"N 76°18'53"W	Gray	Short	14.4	None	2.5	Poor	7.4	None	P	1150-1200 Expanded
8 (165a-1)	Don	40°59'05"N 76°29'00"W	Gray	Short	14.9	None	0.0	Poor	7.7	Slight	P	1150-1200 Expanded
9 (164d-3)	Sb	41°02'35"N 76°18'11"W	Tan	Short	12.8	None	0.0	Poor	8.0	None	N	1150-1200
10	Srl	41°00'45"N 76°27'58"W	Tan	Short	14.6	None	0.0	Fair	7.3	None	N	1150-1200

¹ Based on preliminary tests by the U. S. Bureau of Mines, Tuscaloosa Metallurgy Research Laboratory.² Formation: Desc—Catskill Formation, Sherman Creek Member; Dh—Harrell Formation; Dml—Mahantango Formation, lower member; Don—Onondaga Formation; Sb—Bloomsburg Formation; Srl—Rose Hill Formation, lower member.³ Bloating test: N—negative; P—positive.

Lightweight Aggregate

Certain impure clay shales exhibit the property of expanding ("bloating") to a cellular mass when rapidly heated to temperatures of 1000 to 1300 °C (2000 to 2375 °F). This bloating results from the evolution of gases from impurities within the raw material; if gas evolves within the temperature range of vitrification, it will be trapped and expansion will occur (Bush and Sweeney, 1968). A likely cause of bloating in some clay shales is the evolution of carbon dioxide (CO₂) from calcium carbonate (CaCO₃) at high temperatures (O'Neill and Barnes, 1979). Since all bloating samples from the report area have high pH's (7.4 to 8.2), it is probable that their expansion is due to such CO₂ evolution.

Properties of a good lightweight aggregate are as follows (O'Neill and others, 1965):

1. Bloating over a large firing range, of preferably 100 °C (212 °F), but of at least 40 °C (104 °F).
2. Good cell structure encased in a strong, impervious shell.
3. Density ranging from 0.72 to 1.20 gm/cc (45 to 75 lb/ft³).
4. Gradual expansion through the bloating range.
5. Absorption of 0 to 18 percent at the best bloating temperature.

Five samples collected in the report area, four from the Mahantango Formation and one from the Onondaga Formation, showed some potential for the production of lightweight aggregate (Appendix 2). The most promising of these have optimum properties in the range 1150 to 1200 °C (2100 to 2200 °F). One sample from the Mahantango (no. 6) would appear to be only marginally suitable because of its extreme absorptive properties (76.9 percent at 1150 °C [2100 °F]) and lightness (0.59 gm/cc [36.5 lb/ft³] at 1150 °C [2100 °F]).

LIMESTONE

The limestone quarrying industry has a long history in the Bloomsburg area. In fact, the Tonoloway and Keyser limestones have been so intensely exploited for the production of agricultural lime, fluxstone, and construction aggregate over the past century and a half that few favorable quarry sites now exist. The magnitude of quarry operations in the area is well illustrated by the almost continuous line of pits that extends along the north side of U. S. Route 11 for about 4.2 km (2.6 mi) in eastern Scott and western South Centre Townships. Much of the stone removed from these old quarries was used as fluxstone in the iron furnaces at Bloomsburg.

The largest limestone quarry in the mapped area is located about 1.1 km (0.7 mi) northwest of Lime Ridge. The most recent operator of this quarry was the Baker Stone Company of Bloomsburg, producers of quicklime, hydrated agricultural lime, and construction aggregate from about 1930 to 1968 (Miller, 1934; O'Neill, 1964). The total life of quarrying operations at

Lime Ridge probably exceeded 100 years, as the Low Brothers and a Mr. Wooley ran large quarries there in the 1870's (White, 1883).

Chemical-Grade Limestone

Chemical-grade limestones must have a calcium carbonate content of at least 85 percent and a very low silica content. Such stone is used as fluxstone for steel manufacturing, for smokestack scrubbers in coal-fired electric generating plants, and in the manufacture of glass, paint fillers, agricultural lime, etc. The only high-calcium limestones in the report area occur in the upper part of the Tonoloway Formation and, in the extreme southwest, the lower portion of the Keyser Formation (Figure 45). Concerning the Tonoloway, five samples obtained from the upper 12 m (39 ft) in the active Lycoming Silica Sand Company quarry at Grovania (Danville quadrangle) ranged from 86 to 94 percent (Table 2), and six samples taken from the upper 20 m (66 ft) in the abandoned Baker Stone Company quarry at Lime Ridge varied from 89 to 94 percent calcium carbonate (Table 3). The total thickness of good stone in the Tonoloway is believed to be about 30 m (100 ft), based on the above measurements and on I. C. White's stated thickness of 30 m (100 ft) for his Bossardsville (= upper Tonoloway) limestone (White, 1883).

Two thin intervals of high-calcium stone occur in the Keyser Limestone between Danville and Bloomsburg. These beds appear in the Grovania quarry as a bed of fossiliferous, birdseye calcilutite at the base of the formation and a dense, sparry, stromatoporoid bed about 20.1 m (65.9 ft) above the base (Figure 45; Table 2). Both units are about 4 m (13 ft) thick. The basal, high-calcium zone of the Keyser probably extends eastward into the mapped area at least as far as Fishing Creek. It is definitely absent at Lime Ridge, however, where argillaceous, cobbly limestone of the Keyser directly overlies thin-bedded to laminated Tonoloway (see Figure 5). The stromatoporoid bed has been traced eastward into the mapped area and appears in abandoned quarries in Montour Township north of old U. S. Route 11 (Township Route 416). White (1883) observed a similar bed in the Lime Ridge area, but the interval is no longer exposed.

Exploitable reserves of high-calcium stone in the Bloomsburg-Berwick area are very limited. On the south flank of the Berwick anticlinorium, much of the good stone that once protruded above the Olean terrace gravel in the Espy-Almedia-Lime Ridge area has already been quarried. Many of the old quarries have been filled, and commercial and industrial development along U. S. Route 11 precludes future operations. The only feasible site for renewed quarrying appears to be west of Fishing Creek from the U. S. Route 11-Pa. Route 42 interchange to Valley School. Even in this area much of the limestone has been removed to depths of 15 m (49 ft) or more, and serious problems with groundwater flooding and excessive overburden would be encountered in attempting to quarry stone further downdip to the south. At most other places along the south flank, the Keyser-Tonoloway

GROVANIA

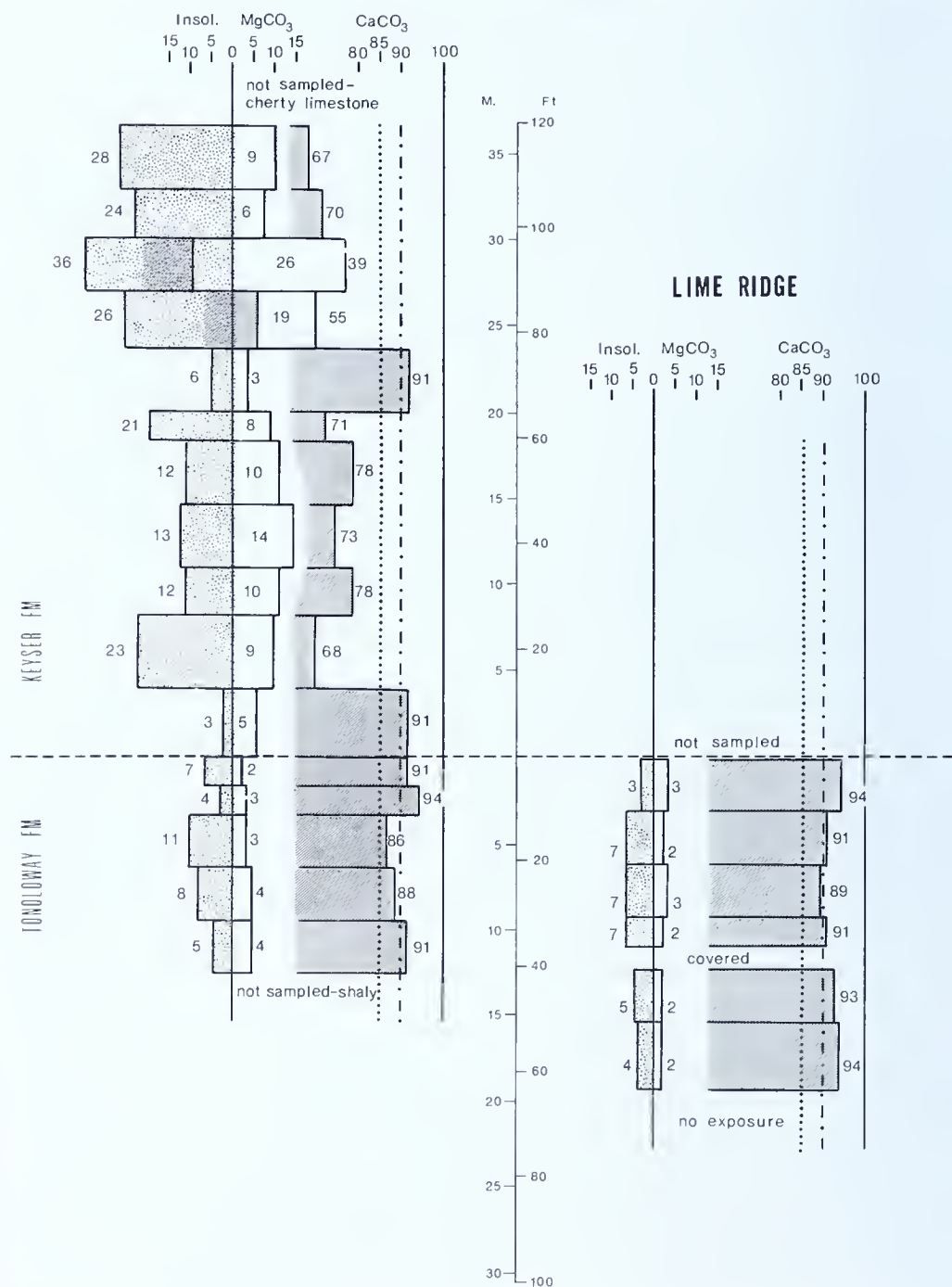


Figure 45. Correlated columns showing chemical analyses and thickness of sampled limestones from the Grovania and Lime Ridge quarries. Gray overprint—CaCO₃; outlined white area—MgCO₃; stipple pattern—insoluble residue; numbers—percent composition by weight. Zero for the CaCO₃ scale does not coincide with zero for MgCO₃ and insoluble-residue scales. (Slightly modified from Faill, 1976.)

Table 2. Chemical Analyses of Limestones from the
Grovania Quarry (Lycoming Silica Sand Company)

Location:

About 300 m (984 ft) north of U. S. Route 11 in Montour Township, Columbia County, 11.0 km (6.8 mi) southwest of Bloomsburg, 40°58'38"N/76°30'58"W, Danville quadrangle.

Sixteen samples were collected from southeast-dipping beds at the west end of a large open pit in an area of active quarrying.

Each sample comprises a composite of fresh fragments (collected at intervals of about 0.3 m, or 1.0 ft) from consecutive stratigraphic units. Sampled by J. D. Inners and B. J. O'Neill, Jr., December 5, 1975. Chemical analyses by U. S. Bureau of Mines.

Samples 1-5 are from the uppermost Tonoloway Formation. Samples 6-16 are from the Keyser Formation.

Not sampled: Calcarenite, medium-dark-gray, cherty, fossiliferous; grades up into sandstone, medium- to coarse-grained, calcareous, fossiliferous. Old Port-Keyser contact (top of sampled interval).

Sample 16: Calcisiltite, medium- to thick-bedded, somewhat dolomitic; shale interbeds.

Sample 15: Calcisiltite, laminated to thin-bedded, shaly.

Sample 14: Calcisiltite, thick-bedded, dolomitic.

Sample 13: Calcisiltite, platy, shaly, dolomitic; laminae of fine calcarenite.

Sample 12: Stromatoporoid bed, massive, medium-gray, sparry.

Sample 11: Shale, calcareous, dark-gray to bluish-gray.

Sample 10: Calcisiltite, dark-gray to bluish gray, argillaceous; shaly at top.

Sample 9: Calcisiltite, medium-light-gray, very fossiliferous; profuse *Halysites* (coral) in upper 1.5 m (4.9 ft); chert nodules at base.

Sample 8: Calcarenite, medium-light-gray, fossiliferous.

Sample 7: Calcisiltite and calcarenite, argillaceous, cobbly weathering.

Sample 6: Calcilutite to fine calcisiltite, birdseye, fossiliferous.

Keyser-Tonoloway contact.

Sample 5: Calcilutite to fine calcisiltite, thick-bedded, medium-dark- to dark-gray, birdseye.

Sample 4: Calcisiltite, thick-bedded, somewhat laminated.

Sample 3: Calcisiltite, laminated, shaly.

Sample 2: Calcisiltite, laminated.

Sample 1: Calcisiltite, laminated (bottom of sampled interval).

Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Thickness (m)	3.0	3.0	3.0	1.8	1.6	4.0	4.3	2.7	3.7	3.7	1.7	3.7	3.3	3.0	2.7	3.6
(ft)	(9.8)	(9.8)	(9.8)	(5.9)	(5.2)	(13.1)	(14.1)	(8.9)	(12.1)	(12.1)	(5.6)	(12.1)	(10.8)	(9.8)	(8.9)	(11.8)
SiO ₂	3.5	6.8	5.0	3.4	5.2	2.8	14.9	10.3	8.7	9.0	13.0	5.2	19.0	27.5	19.5	15.4
Al ₂ O ₃	.7	.8	.9	.5	.3	.2	3.0	1.0	1.1	1.6	3.4	.4	2.8	4.9	2.4	3.3
Fe ₂ O ₃	.20	.39	.37	.18	.18	.26	1.00	.58	.40	.44	.75	.20	.72	1.16	1.08	.86
MgO	2.1	1.8	1.7	1.4	1.1	2.5	4.2	4.7	6.8	4.8	4.0	1.6	9.4	12.5	3.3	5.1
CaO	51.5	49.0	50.0	54.0	50.9	51.3	39.0	43.3	43.0	43.0	40.6	51.0	32.4	22.1	41.8	42.6

Table 2. (Continued)

Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Na ₂ O	.03	.04	.02	.03	.02	.01	.11	.12	.23	.24	.17	.07	.46	.35	.34	.22
K ₂ O	.20	.28	.26	.23	.13	.11	.89	.34	.51	.57	.88	.19	.81	1.3	.52	.96
P ₂ O ₅	.03	.03	.03	.02	.03	.02	.05	.04	.05	.04	.05	.02	.04	.05	.05	.05
Loss on ignition	41.7	40.3	41.0	42.0	41.1	42.7	34.2	38.8	38.8	38.9	35.3	41.0	33.3	29.0	29.2	30.4
Total S,																
as SO ₃	.45	.61	.37	.23	.34	.28	1.9	.65	.65	1.07	1.88	.42	.82	.78	1.49	.86
Sulfate S,																
as SO ₃	.07	.07	.07	.06	.13	.06	.10	.06	.20	.12	.13	.06	.08	.09	.10	.12
Sum	100.48	100.12	99.72	102.05	99.43	100.24	99.35	99.89	100.44	99.78	100.16	100.16	99.83	99.73	99.78	99.87
Insoluble residue	5.1	8.4	11.2	3.5	6.6	3.4	22.9	12.3	12.8	12.1	20.8	5.7	26.0	34.4	20.1	21.0
MgCO ₃ ¹	4.33	3.78	3.42	2.84	2.31	5.22	8.61	9.88	13.60	10.15	8.19	3.34	18.66	25.54	6.48	9.39
CaCO ₃	90.53	87.77	85.79	93.60	91.07	91.37	68.27	77.66	73.44	77.59	70.92	90.86	54.89	38.54	70.01	66.91
Insoluble residue	5.15	8.46	10.79	3.55	6.62	3.42	23.11	12.46	12.99	12.26	20.89	5.80	26.45	35.92	23.52	23.71

¹ Assuming all L.O.I. is CO₂, recalculated to 100 percent.

Table 3. Chemical Analyses of Limestone from the Lime Ridge Quarry (abandoned)

Location:

About 75 m (250 ft) north of U. S. Route 11 and 1.0 km (0.6 mi) northwest of Lime Ridge, South Centre Township, Columbia County, 41°01'45"N/76°21'11"W, Mifflinville quadrangle.

Six samples were collected from southeast-dipping Tonoloway Limestone near middle of quarried area.

Each sample comprises a composite of fresh fragments (collected at intervals of 0.3 m, or 1.0 ft) from distinctive stratigraphic units. Sampled by J. D. Inners and B. J. O'Neill, Jr., December 17, 1975. Chemical analyses by U. S. Bureau of Mines.

All samples were collected from the upper part of the Tonoloway Formation. Samples are consecutive except for a 1.5-m (4.9-ft) covered interval between samples 2 and 3.

Not sampled: Calcisiltite, medium-dark- to dark-gray, lumpy, argillaceous, fossiliferous (Keyser).
Keyser-Tonoloway contact (top of sampled interval).

Sample 6: Calcisiltite and calcituffite, laminated, medium-dark - to dark-gray; laminae of fine calcarenite; very thin shale partings in lower part.
 Sample 5: Calcisiltite, laminated, platy; thin bands and laminae of fine calcarenite.
 Sample 4: Calcisiltite, laminated, platy, fossiliferous (ostracodes); thin shale partings.
 Sample 3: Calcisiltite, laminated, platy.
 Sample 2: Calcisiltite, laminated, platy, medium-gray.
 Sample 1: Calcisiltite, laminated, platy (bottom of sampled interval).

Sample no.	1	2	3	4	5	6
Thickness (m) (ft)						
SiO ₂	4.1 (13.5)	3.0	1.7 (5.6)	3.0 (9.8)	3.0 (9.8)	3.0 (9.8)
Al ₂ O ₃		2.3	5.1	6.6	5.3	2.9
Fe ₂ O ₃		.5	.9	1.1	.8	.5
MgO		.20	.30	.60	.61	.20
CaO		1.0	1.2	1.6	1.1	1.3
Na ₂ O		52.5	51.5	49.0	50.6	52.9
K ₂ O		.02	.02	.08	.03	.02
P ₂ O ₅		.17	.28	.41	.25	.14
Loss on ignition		.03	.03	.04	.04	.04
Total S, as SO ₃	42.1	42.0	40.9	38.7	40.7	41.3
Sulfate S, as SO ₃	.44	.39	.45	.67	.31	.31
Sum	.02	.05	.22	.13	.05	.00
Insoluble residue	99.98 3.9	99.90 4.5	100.90 6.5	98.93 6.7	99.79 6.9	99.61 3.1
MgCO ₃ ¹	2.10	2.27	2.48	3.42	2.31	2.71
CaCO ₃	93.97	93.21	90.95	89.46	90.72	94.08
Insoluble residue	3.93	4.52	6.56	7.12	6.97	3.21

¹ Assuming all L.O.I. is CO₂, recalculated to 100 percent.

interval is covered by terrace gravels to depths of at least 6 m (20 ft). Good quarry sites are equally scarce on the north side of the anticlinorium, primarily due to a thick cover of Muncy Till in many areas and to probable thinning or elimination of the Keyser-Tonoloway interval along the Light Street fault. Should the demand warrant possible quarry development, site preparation will have to be carefully planned according to the surficial and geological conditions described above.

PARTICULATE ANTHRACITE COAL

The alluvial and outwash deposits in the Susquehanna River contain significant amounts of particulate anthracite coal that has washed downstream from the Northern and Eastern Middle Anthracite basins. Coal in the Holocene alluvium is mainly the result of coal mining activity during the last century and a half, whereas that in the outwash originated through direct erosion of outcropping coal beds by water or glacial ice. The coal-rich beds range from well-sorted, fine- to medium-grained quartz-lithic sand to moderately sorted, pebbly gravels. Because of its light specific gravity (1.5 as compared to 2.65 for quartz grains), the coal tends to be somewhat coarser than the modal grain size of the sediment as a whole. Although the coal is mostly decomposed to soft, black powder within the oxidized zone of the Olean outwash deposits, it is generally fresh and of good quality in unoxidized outwash and in Holocene alluvium.

Throughout the first half of this century, dredging of particulate anthracite coal was a thriving industry along many of the creeks and rivers that drain the anthracite fields. Prior to 1900 the coal was recovered mainly as a by-product of sand and gravel operations, but by 1905 commercial operations geared solely to sedimentary coal production had emerged. Of the eight "river" coal producers cited by Sisler and others (1928) as active along the North Branch of the Susquehanna River in the 1920's, four worked out of Espy and Almedia. In 1925 these four operators produced about 10,669 tons of marketable coal. A large operation at Hicks Ferry, Luzerne County, 8.5 km (5.3 mi) upstream of Berwick produced 64,593 tons that same year. The coal was used mainly for electric power generation and for the manufacture of briquets. Apparently production of particulate anthracite coal in the North Branch valley ceased sometime in the late 1940's or early 1950's.

As a result of current high coal prices and the likelihood of their continued escalation, recovery of river coal may again become a mildly attractive commercial venture in the Bloomsburg area. Especially promising areas are below Mifflinville and opposite Espy and Almedia, where low wooded islands serve as baffles to retard swift-moving currents and promote deposition of sediment, especially on the downstream ends of the islands. Another reach of the Susquehanna that may yield significant amounts of particulate coal lies downstream of the mouth of Catawissa Creek, one of the major streams draining the Eastern Middle field.

ZINC AND LEAD

One of the major zinc and lead occurrences in the Valley and Ridge province of Pennsylvania is situated on the north side of the Susquehanna River near Almedia, about 5.2 km (3.2 mi) east-northeast of Bloomsburg (41°01'12"N/76°23'14"W). Stephenson (1947), Earl (1950), and Smith (1977) have discussed the mining history, geologic setting, and mineralization of the Almedia deposit.

Zinc and lead mineralization was discovered at Almedia during limestone quarrying operations early in the nineteenth century. In about 1816, New York investors attempted to develop the ores in paying quantities, and an adit—the Webb Mine—was driven into the steep limestone bluff at the north edge of the broad Susquehanna gravel terrace (Cleaveland, 1816; White, 1883). Little came of this early mining venture, probably because sphalerite—the dominant ore—could not be smelted profitably at the time (Wedow and others, 1968). For decades thereafter, no systematic attempt was made to exploit the Almedia ore body.

In 1900-1903, the Almedia Lead and Zinc Mining Company undertook the only significant development of the Almedia deposit. The dumps and abandoned mine workings that are evident on the west side of the gap cut by a small stream through the limestone ridge, 120 m (390 ft) north of Charlie's Farm Market, date from this period. Operations consisted of an open pit, an air shaft, and two working shafts (Figure 46). Mining was carried to a depth of more than 30 m (100 ft). According to Earl (1950), an \$80,000 concentrating plant on the site processed about 1900 short tons of crude ore and shipped \$10,000 worth of concentrates to Germany for reduction. Mining operations ceased after a worker was killed in the hoist bucket (Smith, 1977).

As part of a post-World War II strategic minerals study, the U. S. Bureau of Mines (U.S.B.M.) in the spring of 1949 drilled four boreholes aggregating 343.3 m (1,126 ft) to investigate the ore body at Almedia (Earl, 1950; Figure 46). Later in the year, the owners of the property dewatered the old 1900-1903 workings to the 13.5-m (44-ft) level. When the mine became accessible, Bureau of Mines personnel were able to survey a portion of the old mine (Figure 46).

Mineralization in the Almedia area is in the middle and lower portion of the Tonoloway Formation. Sphalerite (ZnS) and galena (PbS) occur in calcite veins that strike to the northeast, parallel to the strike of bedrock, and dip steeply to the southeast (Earl, 1950). South of the mine area some mineralized veins dip steeply northwestward (Smith, 1977). The U.S.B.M. cores suggest that mineralization extends through a zone about 41.4 m (136 ft) wide; individual sulfide-bearing veins are up to 30 cm (1 ft) thick. The best recorded ore intercept was 2.28 m (7.5 ft) of 14.5 percent zinc and 3.84 percent lead in Hole No. 1 (Earl, 1950). Even though the findings of the U.S.B.M. drilling investigation were not particularly promising, Smith

(1977) believes that additional exploration in the Almedia vicinity is warranted because the boreholes may not have completely tested the ore horizon.

Miller (1925, 1934) reports zinc and lead mineralization in several old limestone quarries on strike with the Almedia mine, but neither Smith (1977) nor the author found sulfides at these localities. However, good cleavages of dark-brown sphalerite do occur in a bed of dark-gray, intensely veined calcisiltite in the Tonoloway Formation about 0.45 km (0.3 mi) northwest of Camp Creasy (41°01'54"N/76°27'06"W) (J. H. Way, personal communication).

IRON ORE

The mining of sedimentary iron ore from the middle Silurian "Clinton" beds was one of the major extractive industries in the central Appalachian region during the middle years of the nineteenth century. In Pennsylvania the ore region extended from Bedford County, northeastward through the famous "Juniata Iron" district of Huntingdon, Mifflin, Juniata, and Snyder Counties, to Columbia County. The large-scale mining of these ores together with the ready availability of limestone for flux and anthracite coal for fuel, allowed self sufficiency of the central and northeastern Pennsylvania iron industry for several decades (Wright and others, 1968). However, the discovery of much larger ore deposits in the Great Lakes region and rapid advances in steel manufacturing technology spelled the doom of the "Clinton" ore industry in Pennsylvania and adjacent states. By the last quarter of the century, the higher grade "Clinton" ores had been exhausted, and the price of steel had declined to such a point that recovery of the lower grade ores was no longer profitable (Lesley, 1892). Today, "Clinton" ores are mined only in the vicinity of Birmingham, Alabama.

The iron ore industry in the Bloomsburg area developed slowly at first, expanded rapidly through mid-century, and declined quite suddenly in the years following the Civil War.¹ Iron ore was first discovered somewhere west of Fishing Creek in Hemlock Township about 1822. Drift mining was initiated soon after samples were assayed, and the ores were hauled to charcoal furnaces south of the Susquehanna River.² Other discoveries soon followed, and by the 1850's, extensive mining was taking place on both sides of the Montour Ridge-Turkey Hill anticlinal highland in Hemlock, Montour, and Scott Townships and the town of Bloomsburg (Figure 47). The first large furnace, that of the Bloomsburg Iron Company (originally the Bloomsburg Railroad and Iron Company) was "blown-in" in 1844 at Irondale in the gap of Fishing Creek north of Bloomsburg. In 1854, McKelvey,

¹ This historical sketch is taken largely from Battle (1887) and Beers (1915).

² Development of the "Clinton" ores in the vicinity of Danville began about 1840 (Stoek, 1892).

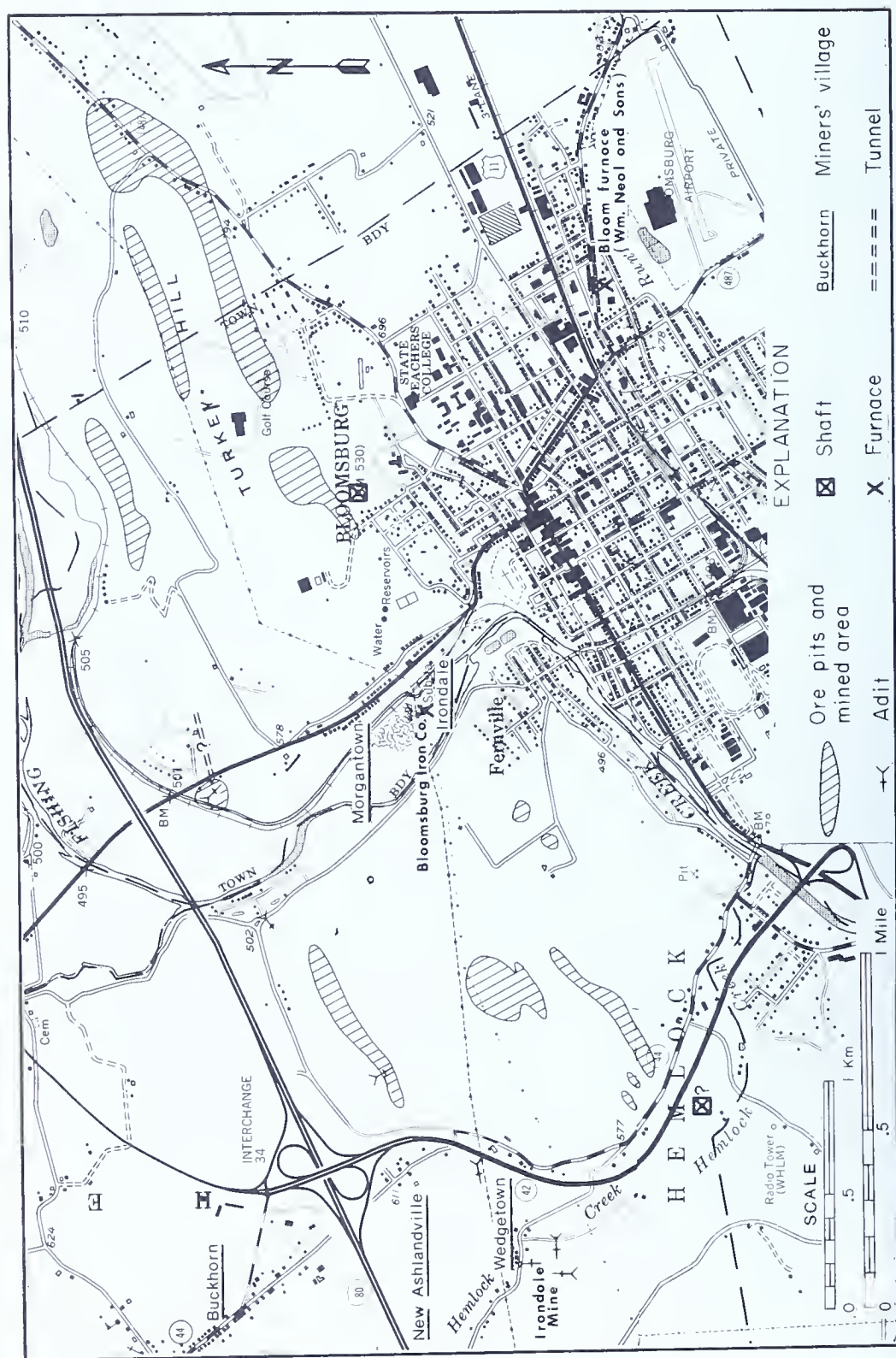


Figure 47. Generalized map of old iron workings in the Bloomsburg area, showing the location of some ore pits,

Neal and Company (after 1873, William Neal and Sons) put into full-blast Bloom furnace, the second large furnace in the Bloomsburg area. The Bloom furnace was located along the canal in the southeast portion of Bloomsburg (near the present airport). Most of the ore for the Bloomsburg Iron Company works came from mines in Hemlock Township, particularly on the north side of the anticlinal ridges. The Bloom furnace was supplied mainly from McKelvey and Neal holdings on Turkey Hill in Scott Township and Bloomsburg. As a result of the success of the Irondale and Bloom furnaces, several ancillary iron manufacturing companies were established in the Bloomsburg area. These included makers of mine cars, car wheels, and blast-furnace equipment. The decline of the iron ore industry in the Bloomsburg area began in the 1870's. By 1875, the Bloom furnace was acquiring most of its ore from New Jersey. Similarly, in the 1880's the Bloomsburg Iron Company was largely using ore from Snyder County. As economic conditions of the old iron works continued to deteriorate, the Bloom furnace was abandoned in 1892 and its competitor in 1893. At the present time, the most obvious reminder of the halcyon days of the old "Clinton" iron-ore industry are the large piles of gray blast-furnace slag remaining at the site of the Bloomsburg Iron Company works (Figure 48).¹



Figure 48. Slag piles of the old Bloomsburg Iron Company furnace on the east side of Fishing Creek in the gap at Fernville, 1.0 km (0.6 mi) north-northwest of the Bloomsburg town square (41°00'33"N/76°28'00"W).

¹ Slag from this site was used as subbase in the construction of Interstate Route 80 at the Mifflinville interchange (R. H. Howe, personal communication).

The two main ores of the Danville-Bloomsburg district are the "Danville fossil-ore" in the upper member of the Rose Hill Formation and the "block ore" in the Centre Member of the same formation. Only the "fossil-ore" was extensively mined in the vicinity of Bloomsburg. This ore consists of thin to medium beds of reddish-brown, highly ferruginous limestone that lie 3 to 10 m (10 to 33 ft) below the Keefer sandstone. The iron occurs as hematite coatings and partial replacements of fossils (mainly fragments of crinoids, brachiopods, and bryozoans). In the mines near Bloomsburg, the "fossil-ore" was highly variable, but typically consisted of two benches—an upper "big vein," about 0.3 m (1 ft) thick, and a lower "little vein" about 0.1 m (0.3 ft) thick (White, 1883). Probably the best localities in the report area to see the ore zone in its typical development are in an old quarry along the abandoned railroad on the south side of Fishing Creek, 2.1 km (1.3 mi) north of the Bloomsburg town square (41°01'16"N/76°27'30"W) and in a natural cliff exposure 1.2 km (0.7 mi) to the east (41°01'26"N/76°26'41"W). Only the "big vein" is developed at these two localities, being 0.3 m (1 ft) and 0.35 m (1.15 ft) thick, respectively.

The "fossil-ore" occurs in two distinct varieties. Most valuable to the nineteenth century miners was the "soft ore," a spongy, thoroughly weathered, near-surface deposit formed by the removal of calcium carbonate from the original, hard, hematitic limestone, or "hard ore." Typical chemical analyses of the two types are given in Table 4. The iron enrichment of the "soft ore" is clearly evident, even considering that one sample of the hard ore (no. 2) is of particularly high grade. According to Rogers (1858), the most propitious areas for mining the "soft ore" were on gently plunging anticlinal noses—as for example on either side of Hemlock Creek and at the east end of Turkey Hill (Figure 47)—where the weathered ore was spread out over large areas near the surface of the ground. The "soft ore" was also removed by open-pit and shallow underground workings along the flanks of the anticlinal highlands. The "hard ore" was mined further down dip using shafts and inclined drifts. Especially good examples of shallow mine drifts and drainage tunnels can be seen at the site of the old Irondale mine on the west side of Hemlock Creek, 1.4 km (0.9 mi) south of Buckhorn (41°00'15"N/76°29'45"W). The author does not know to what depths such workings were carried in the Bloomsburg area, but at Danville one mine is reported to have reached a depth of 152 m (500 ft) (Stoek, 1892).

Rogers (1858) noted that in the smelting of the ores, the lowest proportion of enriched "soft ore" that could be used to insure a high-quality iron was about one third and warned that once the "soft fossil ore" was exhausted, the remaining "hard ore" would be rendered valueless. By his calculations, the "soft ore" (reserves of which in 1847 he showed to be about 1,097,470 metric tons, or 1,210,000 short tons, in the entire Danville-Bloomsburg district) would be used up by 1870. The facts that by the mid-

Table 4. Chemical Analyses of "Fossil Ore," Danville-Bloomsburg District
 Samples 1 and 2 are from Bloomsburg Iron Company mine on
 Fishing Creek (White, 1883); sample 3 is from near
 Danville (Stoek, 1892).

"Hard ore"		
Sample no.	1	2
Fe	17.900 percent	33.700 percent
S	.002	.009
P	.267	.407
CaCO ₃	64.053	41.160
MgCO ₃	5.516	4.116
Siliceous matter	1.520	2.950
"Soft ore"		
Sample no.	3	
Fe ₂ O ₃	67.30 percent (i.e., Fe = 47.1 percent)	
S	.02	
P	.47	
CaO	.86	
MgO	.80	
CO ₂	—	
Al ₂ O ₃	7.94	
SiO ₂	19.28	
H ₂ O	3.50	

1870's most of the ore being mined in the Bloomsburg area was of the "hard fossil-ore" variety and that considerable ore was being imported for use in the iron furnaces indicate how prescient were Rogers' observations.

The "block ore" occurs in the lower part of the Centre Member to the west of the report area and consists of a 0.46- to 0.61-m- (18- to 24-in.) thick bed of highly ferruginous sandstone. Typically this ore contained about 50 percent Fe₂O₃ (Stoek, 1892). Although the "block ore" was the most valuable horizon mined at Danville, it apparently thins and becomes inseparable from the main mass of the "iron sandstone" to the east. Only a few attempts were made to mine this horizon near Bloomsburg, the most notable being that of the Bloomsburg Iron Company on the west side of Hemlock Creek (Rogers, 1858).

Prospects for renewed mining of the "Clinton" hematite ores of the Danville-Bloomsburg district depend to a large extent on improvements in the technology of iron ore beneficiation. The most likely target for commercial development would be the low-grade "iron-sandstone" of the Centre Member. Visual estimates from thin sections of this horizon suggest a hematite content of 10 to 25 percent, or an elemental iron content of 7 to 18 percent. As the lower economic limit for iron ores is now about 25 percent iron (Wright and others, 1968), these ores are clearly subeconomic. Considering

that the thickness of highly ferruginous sandstone in the Centre Member of the Bloomsburg area is about 35 to 40 feet, however, many millions of tons of low-grade iron ore could conceivably be recovered by open-pit or strip-mining methods under the proper economic and technological conditions.

URANIUM

Over the past 30 years numerous uranium occurrences have been reported in the Catskill Formation of northeastern Pennsylvania (McCauley, 1961; Sevon and others, 1978). In Columbia County, uranium mineralization occurs in the basal gray sandstones of fining-upward alluvial cycles in the lower and middle part of the Catskill Formation. The uranium is invariably associated with much larger concentrations of primary and secondary copper minerals in lenses containing abundant carbonized plant debris. Sedimentary features typically found in conjunction with these deposits include erosional channels, claystone-clast conglomerates, and calcareous breccia lenses. Although most of the uranium appears to be disseminated throughout the carbonaceous material in an amorphous form, possibly adsorbed or as an organic compound, some well-crystallized secondary uranium minerals (e.g., uranophane, metazeunerite, and metatorbernite) occur locally. Primary copper minerals are mostly sulfides and include chalcocite, chalcopyrite, bornite, covellite, and digenite. Much more abundant than the primary sulfides are the secondary copper minerals malachite and azurite (carbonates) and chrysocolla (a silicate). Origin of the copper-uranium deposits of Columbia County and nearby areas is discussed in considerable detail by Sevon and others (1978).

At least two and possibly three uranium occurrences are known in the Bloomsburg-Mifflinville area (Figure 49). All are in gray channel sandstones in the Sherman Creek Member of the Catskill Formation. Locality 1 (Prospect 40 in McCauley, 1961) is on the south side of Pa. Route 487, about 1.8 km (1.1 mi) southwest of Orangeville (41°04'13"N/76°25'57"W). Mineralization occurs in several lenticular, carbonaceous zones along the base of a crossbedded, medium-gray, micaceous, calcitic sandstone exposed in a deep roadcut about 75 m (250 ft) east of a sharp bend in the road and directly north of a large abandoned quarry. R. C. Smith, II (personal communication) reports minor amounts of chalcopyrite, digenite(?), and covellite(?) in the sandstone and abundant malachite in the highly carbonaceous zones. Radioactivity is relatively low, the maximum reading obtained on a hand specimen being 0.2 mR/hr. Locality 2 is on the west side of Pa. Route 487 at the north edge of the village of Forks in Fishingcreek Township (41°06'42"N/76°21'50"W). Near the south end of a long roadcut, a 13-cm (5-in.) radioactive horizon rich in carbonized plant fragments, malachite, and chrysocolla occurs 45 cm (1.5 ft) above the base of a 0.75-m- (2.5-ft-) thick, olive-gray, micaceous, calcareous sandstone.

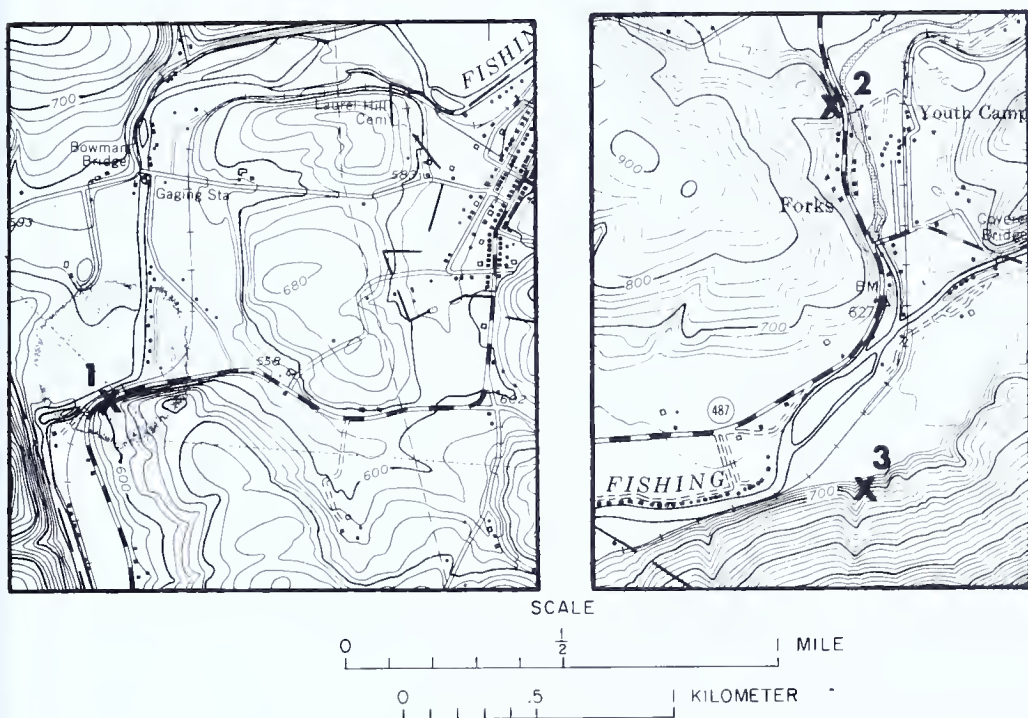


Figure 49. Copper-uranium occurrences in the Bloomsburg and Mifflinville quadrangles. Uranium mineralization has been confirmed at localities 1 and 2, but not at 3.

Platy, roughly rectangular flakes of pale-green metazeunerite, a copper-uranium-arsenic mineral, are conspicuous in the carbonaceous zone (X-ray identification by J. H. Barnes, Pennsylvania Geological Survey). Only a trace of primary copper sulfides was noted. Maximum radioactivity of the numerous hand specimens collected from this site was determined to be 0.5 mR/hr, and several samples showed a radioactivity in excess of 0.2 mR/hr. Locality 3 lies at the foot of the north flank of Knob Mountain, about 1 km (0.6 mi) south of Forks ($41^{\circ}05'57''\text{N}/76^{\circ}21'46''\text{W}$). Profuse secondary copper mineralization occurs in a highly carbonaceous zone in the lower part of a 4-m- (13-ft-) thick, crossbedded, gray sandstone exposed in a high crag just south of the edge of the Fishing Creek floodplain. The sandstone also contains several brownish-weathered (leached) calcareous horizons. Tests for radioactivity have not yet been undertaken at this site, but its similarity to the other two localities suggests that some uranium mineralization probably does occur here.

The presently known occurrences of uranium in the Bloomsburg-Mifflinville area are very small, low-grade deposits. Serious consideration of the commercial development of any of these occurrences would be warranted only by the discovery of significant subsurface extensions of the outcropping uranium concentrations.

OIL AND NATURAL GAS

Exploration for oil and natural gas in the Valley and Ridge province of Pennsylvania has been slow and sporadic over the 125-year history of the petroleum industry in Pennsylvania. Up until 10 or 15 years ago the widespread acceptance of two propositions limited exploration in this part of the Appalachians: namely (1) that the rocks of the fold belt were so strongly altered that intergranular reservoir space was largely eliminated and so intensely fractured and deformed that any hydrocarbons originally present would have escaped to the surface (Roth, 1968) and (2) that natural gas and oil could not exist in areas of very high (greater than 70 percent) carbon ratios (see discussion in Levorsen, 1967). The first of these propositions was negated to a large extent by the discovery of large-scale sole faults, or décollements, in the Valley and Ridge beneath which are potential reservoir rocks much less highly deformed than their near-surface counterparts (Gwinn, 1964). The second, as applied to Pennsylvania, was laid to rest by the discovery of gas fields in Bedford and Lackawanna Counties far to the east of the 80-percent isocarb (Lytle and others, 1958; Grow, 1964). Even so, aside from developmental wells in known fields (mostly in Bedford County), only about three dozen deep wells have been drilled in the entire Pennsylvania fold belt (Harper, 1981).

Although seismic crews have been active in Columbia County for the past several years, no exploratory wells have as yet been drilled in the report area. Probably the main deterrent to drilling within the immediate area has been the poor development of the Ridgeley Sandstone (top of the Old Port Formation), the main deep gas target in the Appalachian basin of Pennsylvania (see p. 20). The virtual absence of the Ridgeley Sandstone in the mapped area is the result of a facies change (i.e., at the time of deposition) of nearshore, shallow-water sands (up to 33 m, or 100 ft, thick near Williamsport) southward into offshore, deep-water muds and cherts (Inners, 1975; Faill and others, 1977). A great thickness of potential reservoir rock exists beneath the Old Port, however. The drilling of wells in the Bloomsburg-Mifflinville area to test these deeper horizons is probably only a matter of time, as the interest in natural gas development continues with the ongoing rise in natural gas prices.

Prior to the summer of 1980, nearly a dozen wells had been drilled within 48 km (30 mi) of the report area.¹ The locations and skeleton logs of seven of these wells are shown in Figures 50 and 51, respectively. The Good, Harrison, Knarr, Krick, Fox, and Solomon wells were typical anticlinal tests, the first four aimed primarily at the Ridgeley horizon, the last at the Middle

¹ The Wilhour No. 1 well (AMOCO Production), drilled in 1979-80 at essentially the same site as the Fox No. 1 well, recently reached a total depth of 4,492 m (14,737 ft). No data have as yet been released.

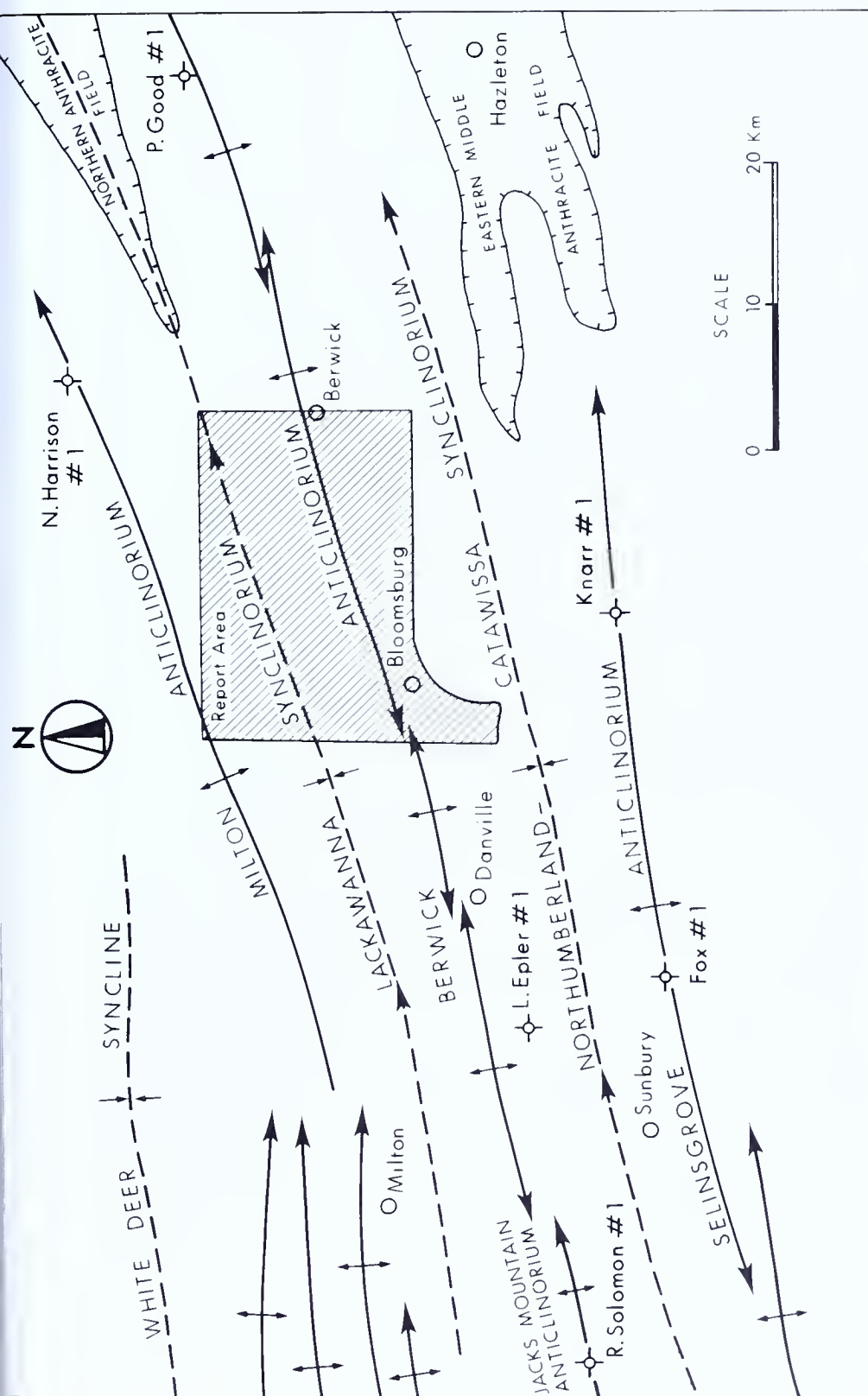


Figure 50. Location and structural setting of exploratory gas wells in the vicinity of the report area. Pertinent data for these wells are presented in Figure 51.

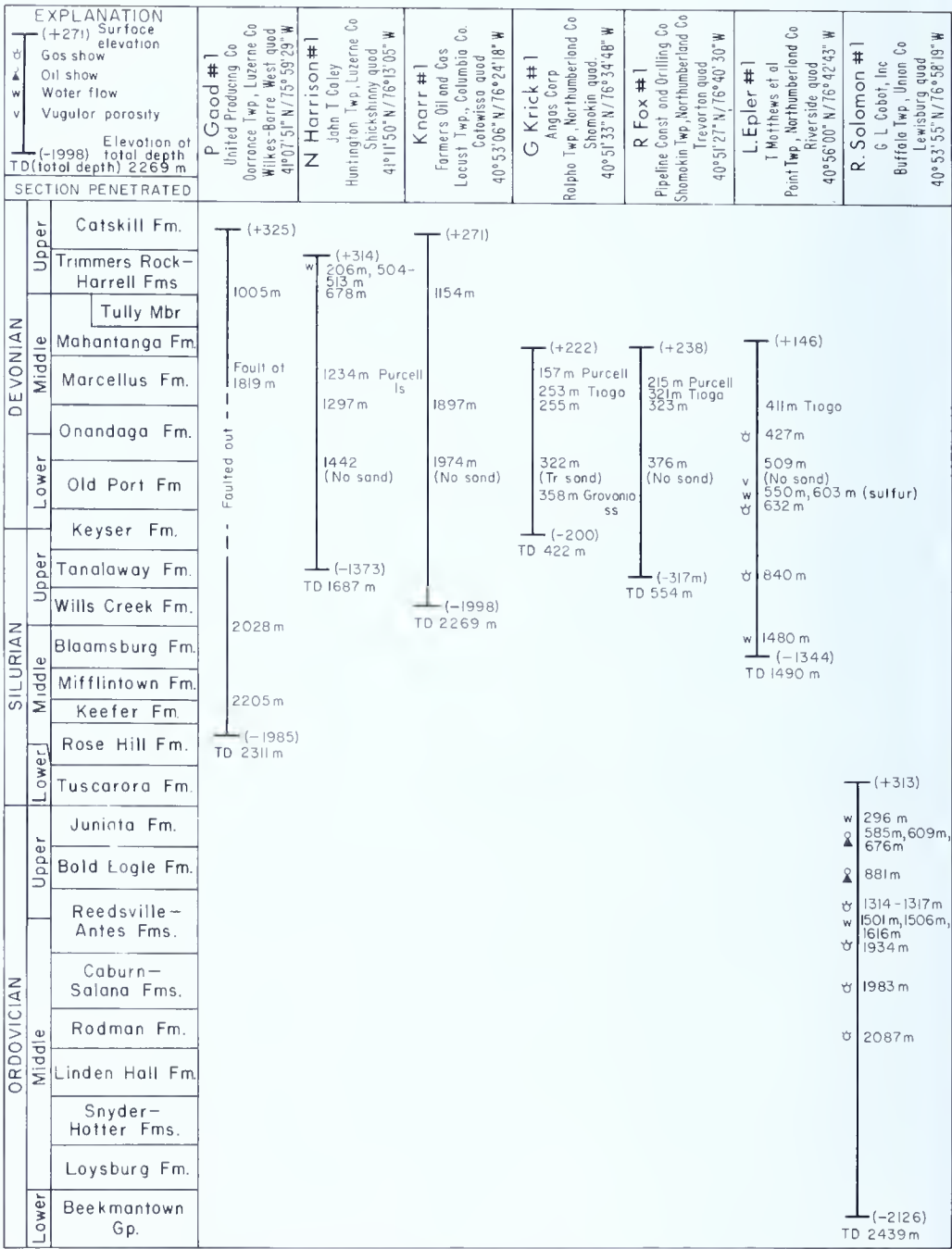


Figure 51. Chart showing the stratigraphic section penetrated by exploratory wells drilled in the vicinity of the Bloomsburg-Mifflinville area, and the locations of oil and gas shows and porosity zones.

Ordovician carbonates. The Epler well may have been an attempt to test a presumed stratigraphic pinchout of the Ridgeley along the south flank of the Berwick anticlinorium. Primarily because of the facies changes noted above, none of the Ridgeley tests found significant sand at the projected ho-

rizon. (The Krick well encountered about 0.3 m, or 1 ft, of tight, siliceous sand at the position of the Ridgeley). The most interesting of these wells is the Solomon No. 1, in which oil or gas shows were reported in the Juniata and Bald Eagle Formations (Upper Ordovician) and the Reedsville-Antes (chiefly Upper Ordovician) and Coburn-Salona-Rodman (Middle Ordovician) intervals. These deep horizons would be likely targets of future exploratory wells in the report area.

Other potential hydrocarbon-bearing units in the subsurface of the Bloomsburg-Mifflinville area are the Tuscarora Formation and the Beekmantown and Upper Cambrian carbonates. Minor natural gas production is obtained from these intervals beneath the Allegheny Plateau in western Pennsylvania, Ohio, and West Virginia, but proper evaluation of their hydrocarbon potential in the Valley and Ridge awaits further drilling.

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GLOSSARY

- Ablation.** All processes by which snow or ice is lost from the surface of a glacier, including melting, evaporation (sublimation), and wind erosion.
- Altonian.** An early to middle phase of the Wisconsinan continental glaciation; lasted from 70,000 to 30,000 years ago.
- Anticlinorium.** A composite anticlinal, or up-folded, structure of regional extent composed of lesser folds.
- Argillaceous.** Containing clay.
- Ball-and-pillow structure.** Hemispherical or kidney-shaped masses of sandstone or siltstone that are formed by foundering of beds into a soft substratum.
- Bioskeletal.** Consisting of whole or broken invertebrate shells or colonial remains.
- Biostrome.** A distinctly bedded, blanket-like mass of rock built by and composed mainly of the remains of sedentary organisms, such as corals, bryozoans, and brachiopods.
- Bioturbated.** Pertaining to sediments disrupted and stirred by organisms.
- Birdseye.** An irregular patch of crystalline calcite in a fine-grained limestone.
- Braided river.** A river that divides into or follows an interlacing network of several small, shallow channels separated from each other by islands or bars.
- Calcarenite.** A limestone consisting predominantly of fragmental calcite particles of sand size.
- Calcilutite.** A limestone consisting predominantly of fragmental calcite particles of clay size.
- Calcirudite.** A limestone consisting predominantly of fragmental calcite particles of gravel size.
- Calcisiltite.** A limestone consisting predominantly of fragmental calcite particles of silt size.

- Carbon ratio.* The percentage of fixed carbon in coal.
- Clast.* An individual grain or fragment of a sediment or rock.
- Coralline.* Composed of fossil corals.
- Décollement.* A detachment surface upon which large-scale sliding has taken place during crustal deformation.
- Devonian.* The geologic time period between 410 and 360 million years ago; pertaining to any deposit formed during this time period.
- Dolosiltite.* A dolostone consisting predominantly of silt-sized dolomite grains.
- Drift.* All rock material transported by a glacier and deposited directly by or from the ice, or by running water issuing from a glacier.
- Epiplanktonic.* Pertaining to organisms that live attached to drifting seaweed or other material in near surface waters.
- Fetid.* Having an offensive odor, commonly caused by the presence of hydrogen sulfide or bituminous matter.
- Frost riving.* The mechanical disintegration of rock due to great pressure exerted by freezing water contained in cracks or pores.
- Gall.* A small, somewhat rounded pellet or fragment, generally of clay, usually embedded in a sandy matrix.
- Gelifluction.* The downslope flow of water-logged surficial material under periglacial conditions.
- Glaciofluvial.* Pertaining to meltwater streams flowing from glaciers or to the deposits formed by such streams.
- Gleization.* The formation of soil mottling due to conditions of intermittent water saturation.
- Holocene.* The portion of the Quaternary Period from 10,000 years ago to the present; pertaining to any deposit formed during this period.
- Ichnofossil.* A sedimentary structure, such as a track, trail, or burrow, resulting from the life activities of an animal.
- Illinoian.* The third of the four major Pleistocene continental glaciations in North America; lasted from about 375,000 to 150,000 years ago.
- Intertidal.* Pertaining to the seashore area between mean high and mean low tides.
- Isocarb.* Lines on a map connecting points of equal fixed-carbon content in coal.
- Kink band.* A tabular, more or less parallel-sided rock zone, within which bedding has been rotated relative to bedding outside the zone.
- Kink plane.* The boundary of a kink band, where bedding is most sharply curved or bent.
- Load cast.* A bulb-shaped protuberance on the bottom of a sandstone or siltstone bed produced by unequal settling on a soft substratum.
- Loess.* Homogeneous, commonly nonstratified deposits of wind-blown silt.
- Meandering river.* A river having a pattern of successive sharp, sinuous curves.

- Mississippian*. The geologic time period between 360 and 330 million years ago; pertaining to any deposit formed during this time period.
- Orogeny*. A period of mountain building; also the process by which the structures (folds, faults, etc.) within mountain areas are formed.
- Pelagic*. Pertaining to marine organisms that inhabit the open ocean, rather than the bottom or shore areas.
- Periglacial*. Pertaining to the region or environment adjacent to a glacier.
- Photic zone*. That part of the sea in which there is sufficient penetration of light to support photosynthesis.
- Pickeringite*. Hydrated magnesium aluminum sulfate, $\text{MgAl}_2(\text{SO}_4)_4 \cdot 22\text{H}_2\text{O}$; characterized by its astringent taste.
- Pleistocene*. The portion of the Quaternary Period from 2 million to 10,000 years ago (the "Ice Age"); pertaining to any deposit formed during this period.
- Prodelta*. The part of a delta complex that is below the effective depth of wave erosion and beyond the delta front.
- Prograding shoreline*. A shoreline that is being built outward into the sea by deposition and accumulation of sediment.
- Provenance*. The area from which the constituent materials of a sedimentary rock or surficial deposit are derived.
- Quaternary*. The time period from 2 million years ago to the present; pertaining to any deposit formed during this time period.
- Regolith*. Soil and fragmented rock lying above, and derived from, the underlying bedrock.
- Regressive*. Pertaining to the retreat of the sea from land areas.
- Rubified*. Referring to a material that has been made red by weathering during a period of warm, moist climate.
- Salt cast*. A secondary filling of a cavity or depression left by the solution of a salt (generally halite) crystal.
- Sangamonian*. The third interglacial stage of the Pleistocene (between the Illinoian and Wisconsinan glaciations); a time of warm, moist climatic conditions that lasted from 150,000 to 70,000 years ago.
- Silurian*. The geologic time period between 435 and 410 million years ago; pertaining to any deposit formed during this time period.
- Slickenside*. A polished and smoothly striated surface that results from friction along a fault plane. Individual striations on this surface are called *slickenlines*.
- Sole marking*. A convex irregularity on the bottom of a sandstone or siltstone bed, formed by infilling of a depression in the underlying bed.
- Stratified drift*. Sorted and layered material deposited by a glacial meltwater stream.
- Stromatolitic*. Pertaining to laminated, commonly dome-shaped sedimentary structures formed in shallow-water carbonate environments through the trapping of sediment by algal mats.

Stromatoporoid. An extinct colonial marine organism, probably related to the sponges.

Subtidal. Pertaining to shallow sea bottoms that lie between mean low tide and a depth of about 90 m (300 ft).

Transgressive. Pertaining to the spread of the sea over land areas.

Turbidite. A sediment or rock deposited from a bottom-flowing current laden with suspended sediment; generally characterized by graded bedding and a distinctive vertical sequence of sedimentary structures.

Proximal turbidites are deposited near the source area of the sediment, whereas *distal* turbidites are deposited far out in the sedimentary basin.

Weathering prism. Prismatic reduction zones in deep, gleized, clayey soils.

Wisconsinan. The last of the four major Pleistocene continental glaciations in North America; lasted from 70,000 to 10,000 years ago.

Woodfordian. A late phase of the Wisconsinan continental glaciation; lasted from 25,000 to 12,000 years ago.

APPENDIX 1

TYPE SECTIONS OF GLEN BROOK TILL AND NESCOPECK LOESS

Glen Brook Till

Location: In a shallow gully just east of a small earth dam on a tributary of Glen Brook, 2.2 km (1.4 mi) north of Foundryville, Briar Creek Township, Columbia County (41°05'56"N/76°14'17"W, Berwick quadrangle).

<i>Unit</i>	<i>Thickness</i>	
	<i>Meters</i>	<i>Feet</i>
2 Colluvial till: light-brown (5YR5/6), ¹ slightly stony silty clay, nonstratified, unsorted. Matrix is moderately plastic. Pebbles constitute about 10 percent of deposit; most are subrounded, deeply to moderately weathered. Moderately sharp transition with underlying in-place till.	0.6	2.0
1 Till: moderate-reddish-brown (10R5/6), stony sandy clay, nonstratified, unsorted, very compact. Matrix is very slightly plastic and has distinct fissility parallel to ground surface. Pebbles and small cobbles make up 25 percent of deposit; mostly subrounded to subangular, moderately weathered to unweathered; many fine-grained clasts are striated; abundant dark manganese and iron staining. Clasts are of diverse lithologies; especially abundant are grayish-red (5R4/2) claystones and medium-light-gray (N6) to light-olive-gray (5Y6/1) sandstones of Catskill derivation.	2.0	6.6
Total	2.6	8.6

Nescopeck Loess

Location: In abandoned pits at the foot of the "River Hill" escarpment, about 0.4 km (0.25 mi) south of Nescopeck, Luzerne County (41°02'45"N/76°12'52"W, Berwick quadrangle).

Comment: At this locality, Nescopeck Loess is banked against a steep bedrock escarpment and is interbedded with thin layers of shale-chip rubble. The loess was blown off the adjacent Olean outwash terrace, probably by northwesterly winds, whereas the shale-chip rubble formed by colluviation off the bedrock slope. Both types of deposit are indicative of a periglacial environment. Although the loess itself is structureless, layering as defined

¹ Color designations are taken from Goddard and others (1948).

by the rubble layers is inclined 25 degrees to the northwest. All measurements are perpendicular to this stratification.

<i>Unit</i>	<i>Thickness</i>	
	<i>Centimeters</i>	<i>Inches</i>
13 Mixed loess and shale-chip rubble: loess is fine sandy silt, predominantly dark yellowish brown (10YR4/2), banded light brown (5YR5/6) to dark yellowish orange (10YR6/6) (bands to 2 cm, or 0.8 in., thick) in lower part, oxidized. Shale chips are dark gray (N3), platy to chippy, mostly 2 to 4 cm (0.8 to 1.6 in.); some larger light-olive-gray (5Y6/1) siltstone plates are also present.	45	17.7
12 Loess: fine sandy silt, mottled moderate brown (5YR4/4) and dark yellowish orange (10YR6/6), nonplastic.	59	23.2
11 Loess: similar to unit 12, but mottled moderate reddish brown (10R4/6) and light brown (5YR5/6); strongly oxidized.	32	12.6
10 Loess: fine sandy silt, somewhat siltier than overlying units, distinctly mottled moderate brown (5YR4/4) and dark yellowish orange (10YR6/6).	41	16.1
9 Shale-chip rubble: chippy, dark-gray (N3) shale fragments, mostly 2 to 3 cm (0.8 to 1.2 in.).	1	0.4
8 Loess: similar to unit 10.	29	11.4
7 Shale-chip rubble: platy and chippy, dark-gray (N3) shale fragments to about 4 cm (1.6 in.) in maximum diameter; also some larger siltstone plates to about 7 cm (2.8 in.) in maximum diameter and 2 cm (0.8 in.) thick.	4	1.6
6 Loess: fine sandy silt, moderate-yellowish-brown (10YR5/4), damp, slightly cohesive, oxidized.	12	4.7
5 Shale-chip rubble: similar to unit 7; largest siltstone fragment is 15 cm (5.9 in.) in maximum diameter and 2 cm (0.8 in.) thick.	11	4.3
4 Loess: similar to unit 6.	14	5.5
3 Shale-chip rubble: similar to unit 7; largest fragments are 5 cm (2 in.) in maximum diameter and 1 cm (0.4 in.) thick.	3	1.2
2 Loess: fine sandy silt, moderate-yellowish-brown (10YR5/4), damp, slightly cohesive, oxidized.	18	7.1
1 Shale-chip rubble: chippy, dark-gray (N3) shale fragments to about 4 cm (1.6 in.) maximum diameter and 0.5 cm (0.2 in.) thick.	3	1.2
Total	272 (2.72 m)	107.0 (8.9 ft)

Lower part of deposit is covered by material that has slumped from above.

APPENDIX 2**TESTS AND ANALYSES OF SELECTED CLAY SHALES¹****Sample 1: Catskill Formation (Sherman Creek Member)****SLOW-FIRING TESTS:**

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Moderate orange (2.5YR6/8)	3	2.5	21.4	37.1	1.74
1050	Moderate orange (2.5YR6/8)	3	2.5	20.4	35.6	1.74
1100	Brownish orange (2.5YR5/8)	4	5.0	12.4	25.6	2.01
1150	Strong brown (2.5YR4/8)	5	5.0	8.3	17.7	2.13
1200	Strong brown (2.5YR4/6)	6	7.5	3.7	8.7	2.33
1250	—	—	Melted	—	—	—

Bloating test: Negative

Sample 2: Harrell Formation**SLOW-FIRING TESTS:**

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Moderate yellow- ish pink to moder- ate orange (5YR7/6)	3	5.0	15.6	28.8	1.85
1050	Light brown to moderate orange (5YR6/6)	3	5.0	11.5	22.6	1.97
1100	Grayish reddish orange (2.5YR6/6)	4	7.5	5.6	12.3	2.20
1150	Light reddish brown (2.5YR5/4)	4	7.5	0.7	1.8	2.35
1200	—	—	Melted	—	—	—
1250	—	—	—	—	—	—

Bloating test: Negative

¹ Based on data obtained from the Tuscaloosa Metallurgy Research Laboratory of the U. S. Bureau of Mines. Chemical and X-ray analyses by John H. Barnes and Robert C. Smith, II, Pennsylvania Geological Survey. See Table 1 for location and physical properties of samples.

² Munsell colors from American Society of Testing and Materials (1975).

Sample 3: Harrell Formation

SLOW-FIRING TESTS:

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Light yellowish brown to moderate orange yellow (7.5YR7/6)	5	2.5	10.7	21.6	2.03
1050	Moderate yellow- ish pink to mod- erate orange (5YR7/6)	6	5.0	9.0	18.8	2.09
1100	Brownish orange (5YR5/6)	7	7.5	2.4	5.5	2.27
1150	Grayish brown (5YR4/2)	8	7.5	0.5	1.2	2.36
1200	—	—	Melted	—	—	—
1250	—	—	—	—	—	—

Bloating test: Negative

CHEMICAL ANALYSIS:

	%
SiO ₂	61.9
Al ₂ O ₃	19.75
Σ“F ₂ O ₃ ”	2.98
MgO	1.12
CaO	0.03
Na ₂ O	0.62
K ₂ O	4.72
TiO ₂	0.96
MnO	0.003
Volatiles (mostly H ₂ O ₁ with trace CO ₂)	7.92

MINERALOGY (X-RAY):

	%
Quartz	23
Mica-smectite	70
Kaolinite	0
Chlorite-vermiculite	4
Feldspar	3
Calcite	0

Sample 4: Mahantango Formation

SLOW-FIRING TESTS:

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Moderate yellow- ish pink to mod- erate orange (5YR7/6)	3	2.5	15.0	28.4	1.89
1050	Brownish orange (2.5YR5/8)	3	5.0	9.9	20.6	2.09

Sample 4: Mahantango Formation (*Continued*)

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1100	Strong brown (2.5YR4/8)	4	5.0	5.7	12.7	2.24
1150	Moderate reddish brown (2.5YR4/4)	4	7.5	1.1	2.6	2.41
1200	—	—	Expanded	—	—	—
1250	—	—	—	—	—	—

BLOATING TESTS (QUICK-FIRING):

Temp. °C	Percent absorption	Bulk density (gm/cc)	Bulk density (lb/ft ³)	Remarks
1050	9.1	1.77	106.7	Slight expansion.
1100	6.4	1.58	98.8	Slight expansion.
1150	7.3	1.23	76.9	Good pore structure.
1200	12.6	0.76	47.4	Good pore structure.

Sample 5: Mahantango Formation

SLOW-FIRING TESTS:

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Moderate orange (2.5YR6/8)	3	2.5	13.82	26.5	1.92
1050	Brownish orange (2.5YR5/8)	3	5.0	9.04	18.8	2.08
1100	Strong brown (2.5YR4/6)	4	5.0	5.1	11.3	2.21
1150	Moderate red- dish brown (2.5YR4/4)	5	5.0	1.4	3.1	2.32
1200	—	—	Expanded	—	—	—
1250	—	—	—	—	—	—

BLOATING TESTS (QUICK-FIRING):

Temp. °C	Percent absorption	Bulk density (gm/cc)	Bulk density (lb/ft ³)	Remarks
1050	10.3	1.52	94.5	Partial expansion.
1100	10.4	1.38	86.0	Partial expansion.
1150	8.3	1.00	62.4	Good pore structure.
1200	13.8	0.73	45.7	Good pore structure (sticky).

Sample 6: Mahantango Formation

SLOW-FIRING TESTS:

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Moderate orange (2.5YR6/8)	3	2.5	11.9	23.6	1.97
1050	Grayish reddish orange (2.5YR5/6)	4	2.5	8.5	17.5	2.06
1100	Strong brown (2.5YR4/6)	4	2.5	5.5	11.5	2.08
1150	—	—	Expanded	—	—	—
1200	—	—	—	—	—	—
1250	—	—	—	—	—	—

BLOATING TESTS (QUICK-FIRING):

Temp. °C	Percent absorption	Bulk density (gm/cc)	(lb/ft ³)	Remarks
1000	55.4	1.46	91.0	Slight expansion.
1050	65.0	1.16	72.1	Slight expansion.
1100	85.6	0.83	51.9	Good pore structure.
1150	76.9	0.59	36.5	Good pore structure (sticky).

Sample 7: Mahantango Formation

SLOW-FIRING TESTS:

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Moderate yellow- ish pink to moderate orange (5YR7/6)	3	2.5	14.1	26.7	1.89
1050	Grayish reddish orange (2.5YR6/6)	3	2.5	9.6	19.7	2.04
1100	Grayish reddish orange (2.5YR5/6)	4	5.0	7.2	15.4	2.13
1150	Moderate red- dish brown (2.5YR3/4)	5	5.0	3.5	7.7	2.17

Sample 7: Mahantango Formation (*Continued*)

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1200	—	—	Expanded	—	—	—
1250	—	—	—	—	—	—

BLOATING TESTS (QUICK-FIRING):

Temp. °C	Percent absorption	Bulk density (gm/cc)	Bulk density (lb/ft ³)	Remarks
1050	7.9	1.85	115.1	Slight expansion.
1100	11.3	1.63	101.5	Slight expansion.
1150	12.4	1.05	65.3	Good pore structure.
1200	11.9	0.84	52.5	Good pore structure (sticky).

Sample 8: Onondaga Formation

SLOW-FIRING TESTS:

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Moderate yellow- ish pink to moderate orange (5YR7/6)	3	2.5	12.5	24.3	1.95
1050	Brownish orange (2.5YR5/8)	4	5.0	7.2	15.4	2.14
1100	Strong brown (2.5YR4/8)	4	5.0	4.9	10.8	2.23
1150	Moderate red- dish brown (2.5YR4/4)	6	7.5	1.6	3.7	2.29
1200	—	—	Expanded	—	—	—
1250	—	—	—	—	—	—

BLOATING TESTS (QUICK-FIRING):

Temp. °C	Percent absorption	Bulk density (gm/cc)	Bulk density (lb/ft ³)	Remarks
1050	11.26	1.53	146.01	Slight expansion.
1100	12.81	1.31	81.74	Slight expansion.
1150	15.95	1.01	63.02	Good pore structure.
1200	11.26	1.00	62.40	Good pore structure (sticky).

Sample 9: Bloomsburg Formation

SLOW-FIRING TESTS:

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Grayish reddish orange (2.5YR6/6)	3	2.5	10.2	20.8	2.05
1050	Grayish reddish orange (2.5YR5/6)	4	2.5	6.2	13.7	2.20
1100	Strong brown (2.5YR4/6)	4	5.0	4.2	9.5	2.28
1150	Moderate red- dish brown (2.5YR4/4)	5	5.0	1.7	3.9	2.33
1200	—	—	Melted	—	—	—
1250	—	—	—	—	—	—

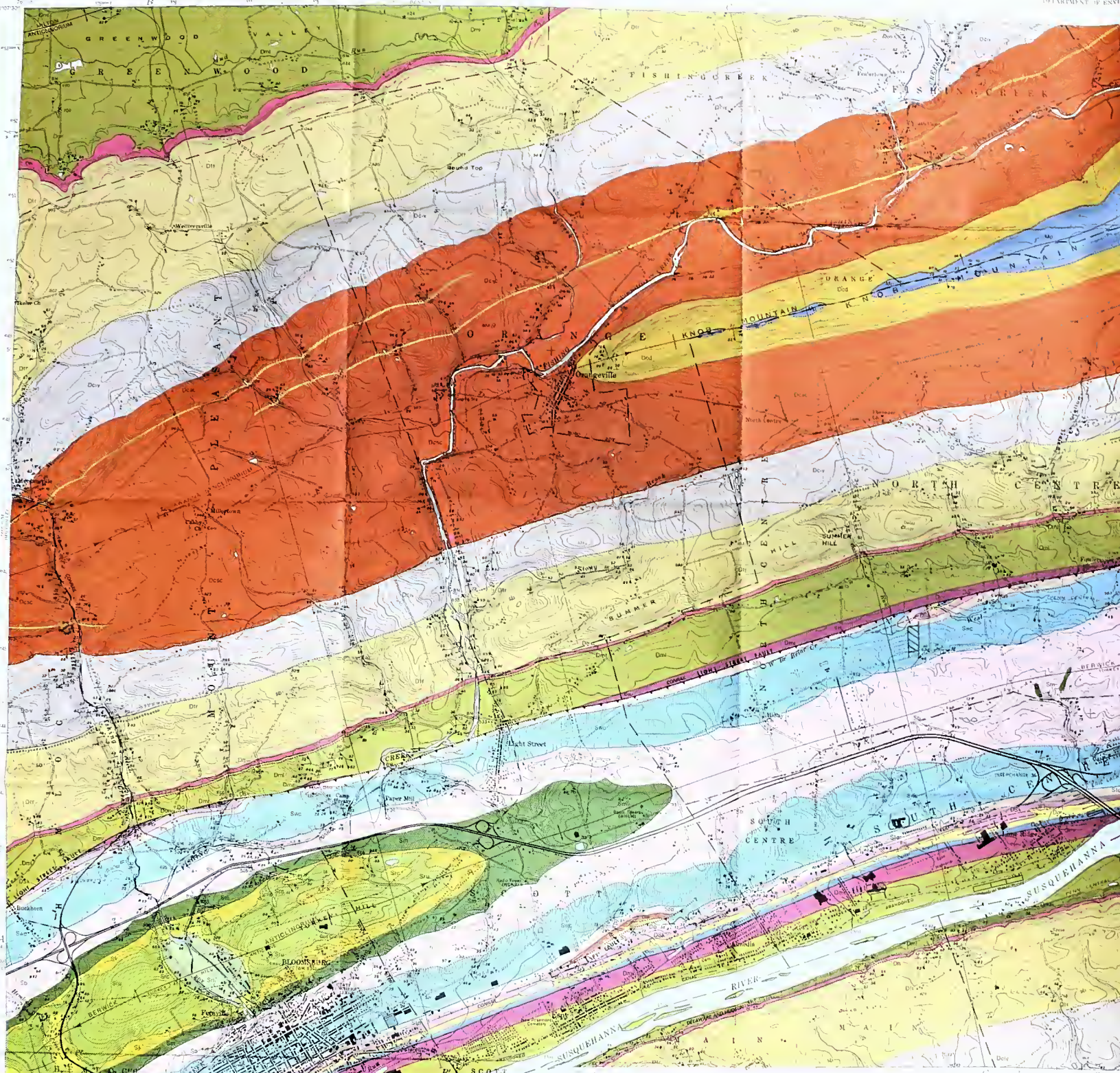
Bloating test: Negative

Sample 10: Rose Hill Formation (lower member)

SLOW-FIRING TESTS:

Temp. °C	Color (Munsell designation ²)	Mohs' hardness	Percent linear shrinkage	Percent absorption	Percent apparent porosity	Bulk density (gm/cc)
1000	Moderate yellow- ish pink to moderate orange (5YR7/6)	3	2.5	12.9	25.7	1.99
1050	Moderate orange (2.5YR6/8)	3	5.0	10.4	21.5	2.07
1100	Grayish reddish orange (2.5YR5/6)	4	5.0	5.9	13.3	2.25
1150	Moderate reddish brown (2.5YR4/4)	5	5.0	2.0	4.8	2.36
1200	—	—	Melted	—	—	—
1250	—	—	—	—	—	—

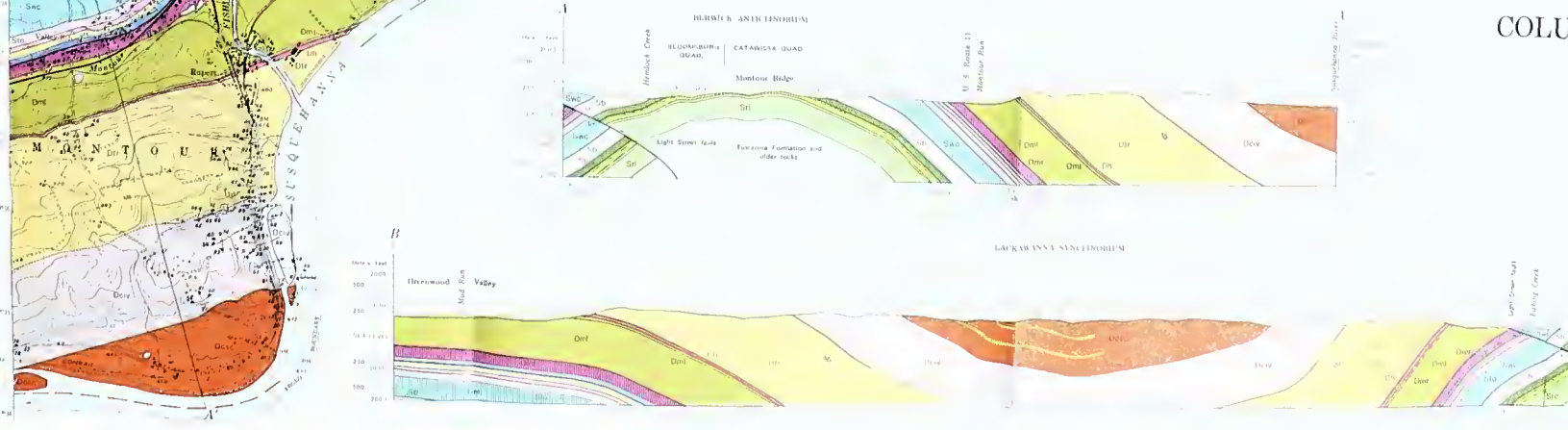
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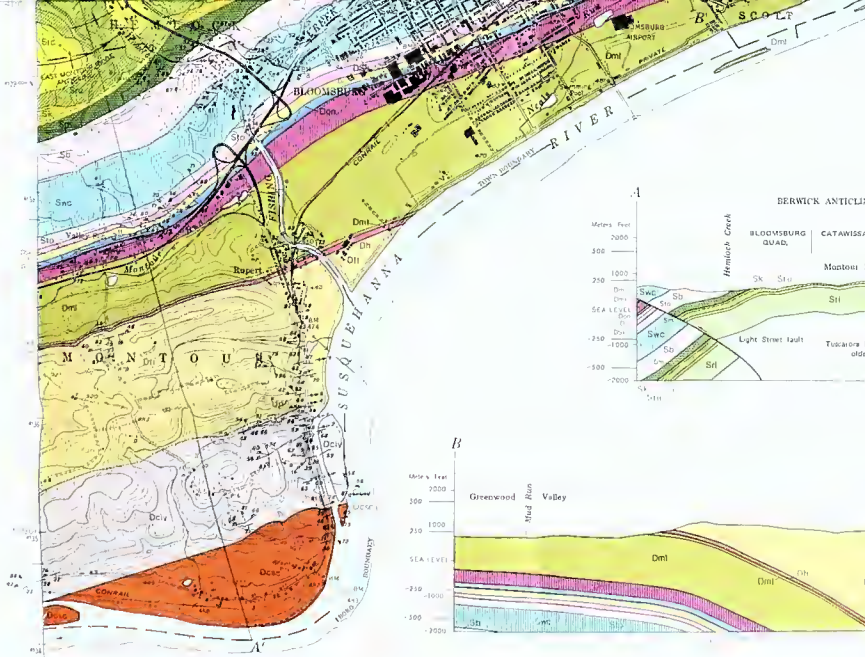
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Base map from U. S. Geological Survey
Bloomsburg, Mifflinville, and Catwissa 7-1/2
minute quadrangles

CROSS SECTIONS

(Horizontal scale same as map scale, no vertical exaggeration)



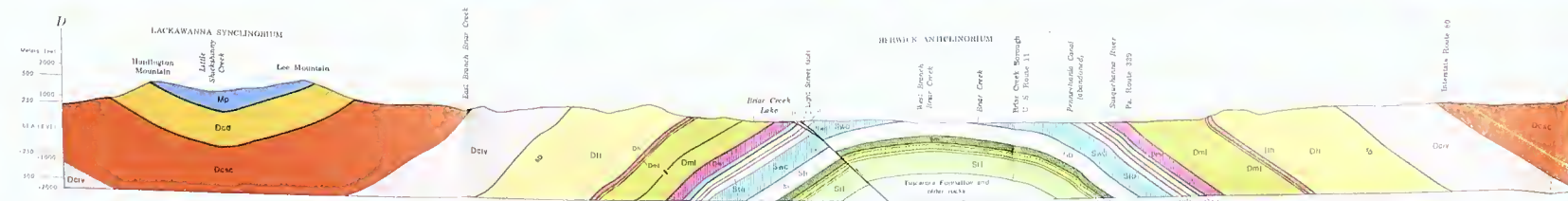
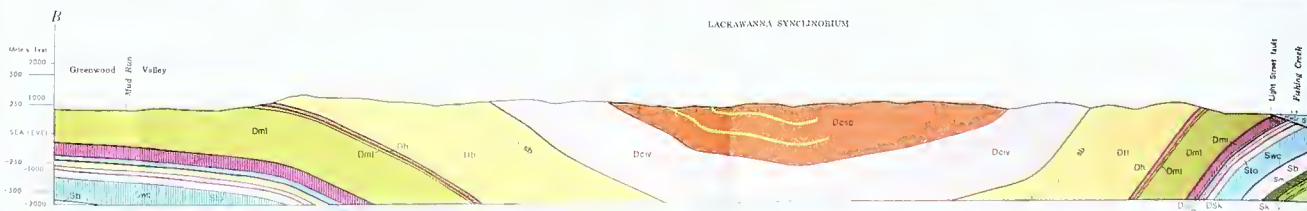
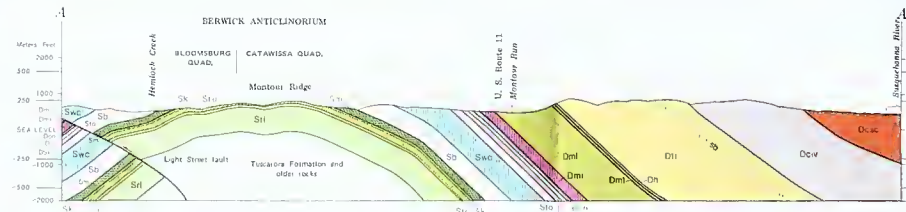
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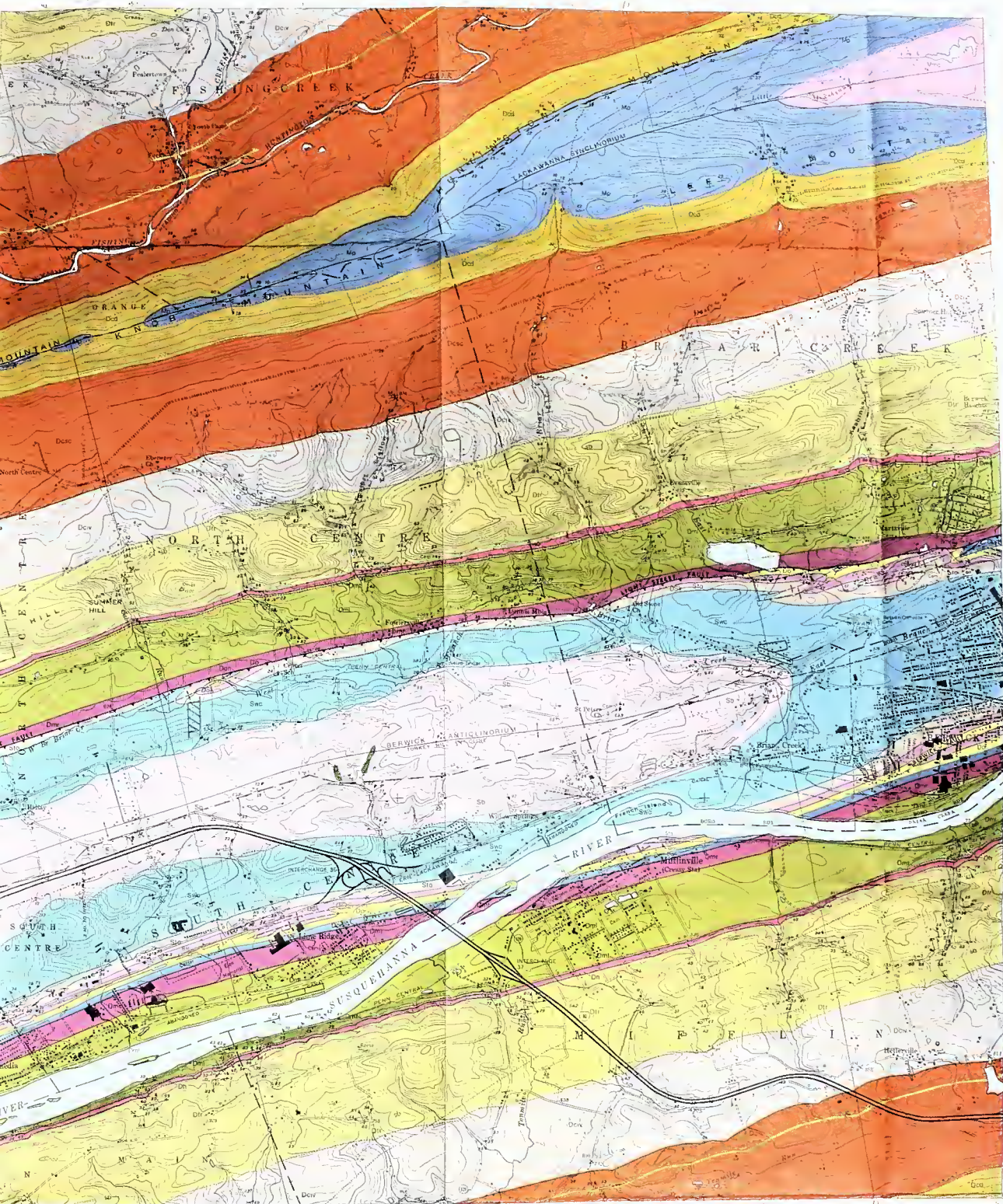
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 Base map from U. S. Geological Survey
 Bloomsburg, Mifflinville, and Chawassa 7 1/2
 minute quadrangles.

CROSS SECTIONS

(Horizontal scale same as map scale; no vertical exaggeration)



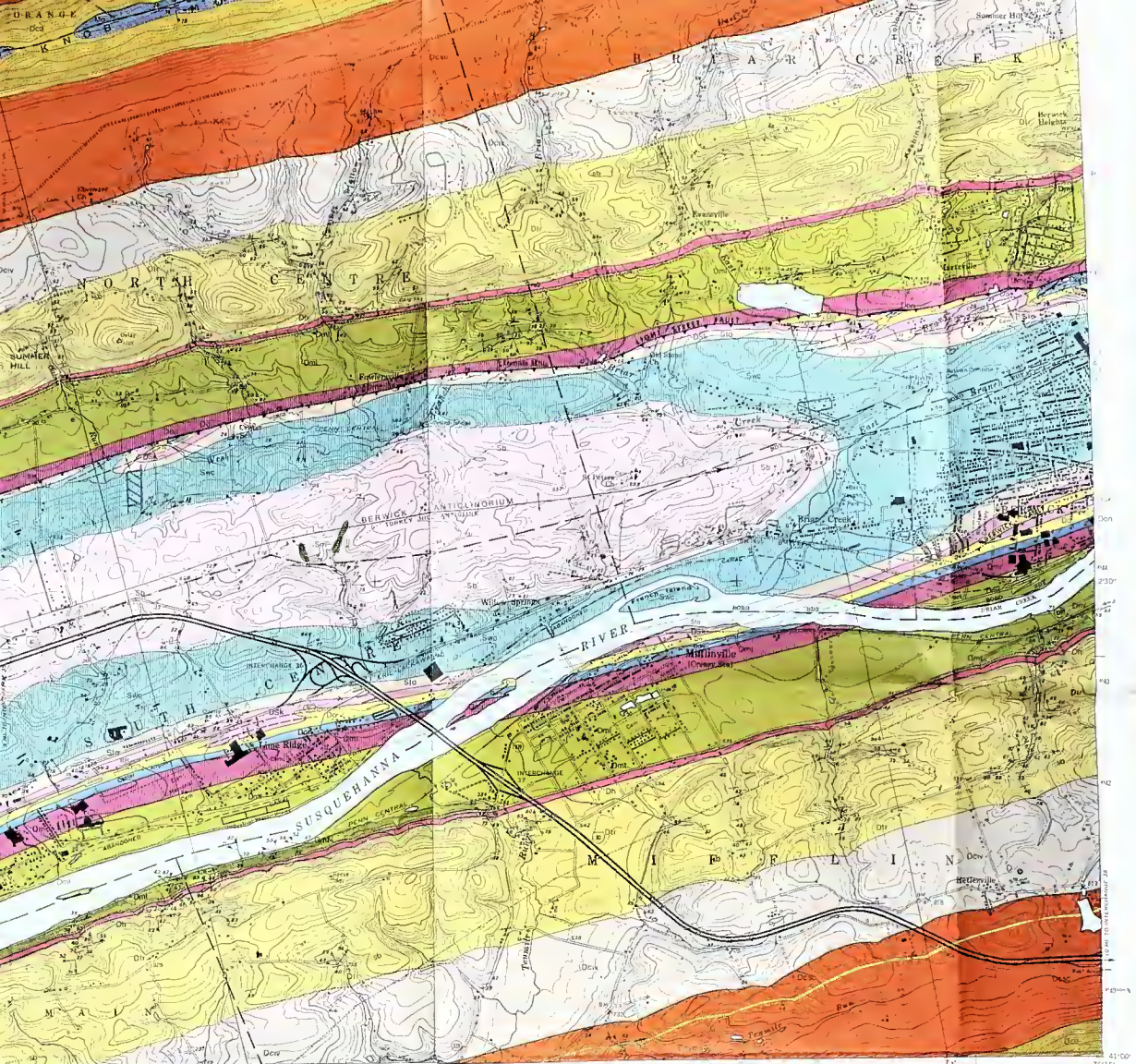
BED
 BLOOMSBURG
 AND PART
 COLUMBIA



Geology based on field mapping from 1977-80.
Vern E. VanDusen, Cartographer

BEDROCK GEOLOGIC MAP OF THE BLOOMSBURG AND MIFFLINVILLE QUADRANGLES AND PART OF THE CATAWISSA QUADRANGLE, COLUMBIA COUNTY, PENNSYLVANIA

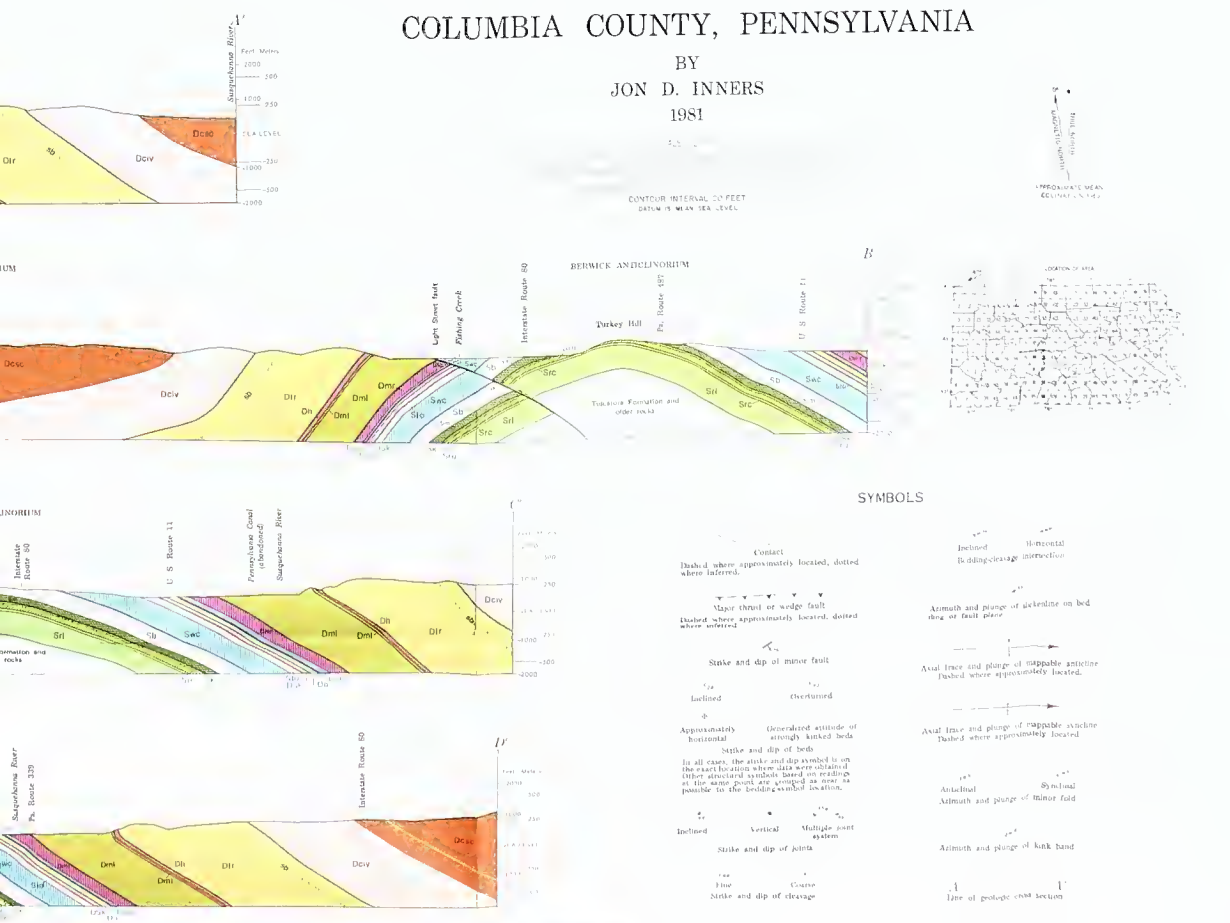
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1981

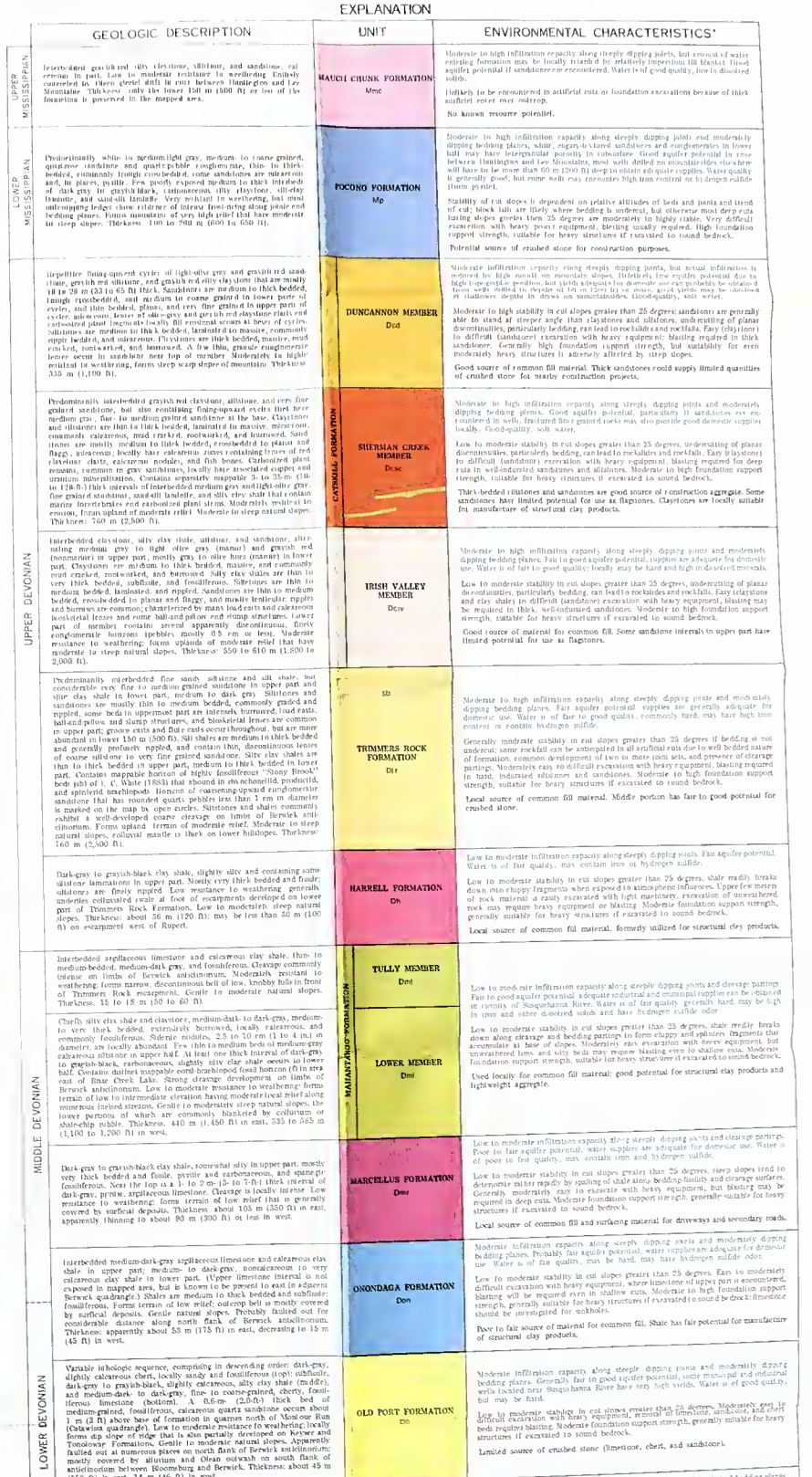


Geology based on field mapping from 1977-80,
Albert E. VanOlden, Cartographer

BEDROCK GEOLOGIC MAP OF THE BLOOMSBURG AND MIFFLINVILLE QUADRANGLES AND PART OF THE CATAWISSA QUADRANGLE, COLUMBIA COUNTY, PENNSYLVANIA

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JON D. INNERS
1981

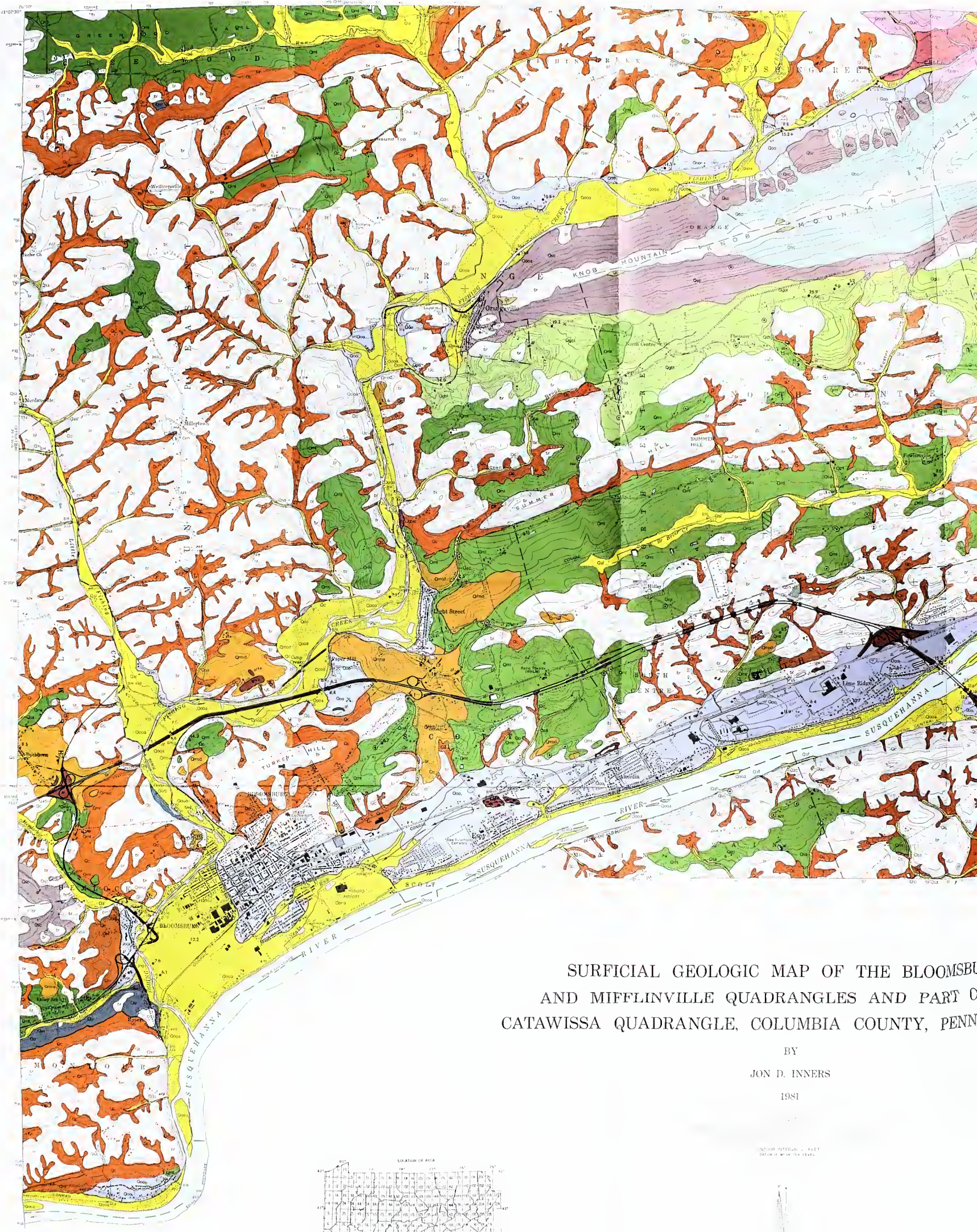




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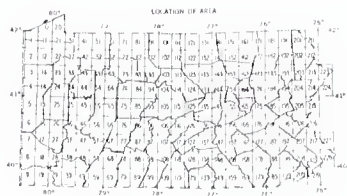
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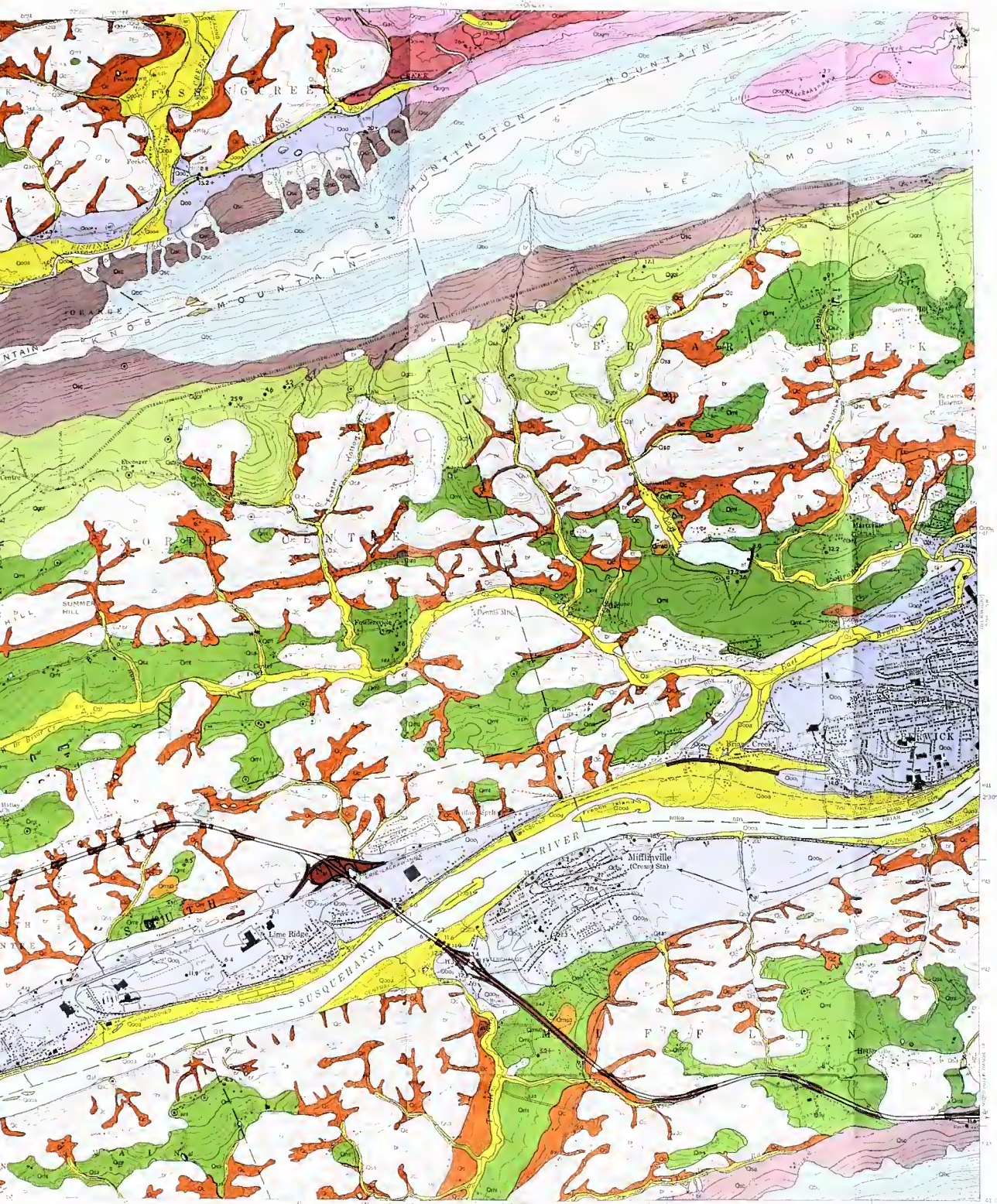
slopes tend to deteriorate rapidly
rocks to physical and chemical
equipment, depending on degree



SURFICIAL GEOLOGIC MAP OF THE BLOOMSBURG
AND MIFFLINVILLE QUADRANGLES AND PART OF
CATAWISSA QUADRANGLE, COLUMBIA COUNTY, PENN.

BY
JON D. INNERS
1981





AL GEOLOGIC MAP OF THE BLOOMSBURG LINVILLE QUADRANGLES AND PART OF THE ADRANGLE, COLUMBIA COUNTY, PENNSYLVANIA

BY
JON D. INNERS

1981

AT 1:50,000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL



SYMBOLS

Contour
Dashed where approximately located

Top
Base
Stream - scarp

Channelway

Well hole

Fossil locality

Spring

Thickness, in meters, of surficial deposits in water
with and without

Gravel pit

